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STUDY TO EVALUATE THE EFFECT OF EVA ON PAYLOAD SYSTEMS

FINAL REPORT

VOL. II. TECHNICAL ANALYSES

NAS2-8429 NOVEMBER 25, 1975

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INTRODUCTION

The final report of the "Study to Evaluate the Effect of EVA on Payload Systems", consists of three volumes as follows:

Volume I	Executive Summary
Volume II	Technical Analyses
Volume III	Cost Data (Limited Distribution)

Volume II provides detailed descriptions of the technical analyses performed in the course of the study.

STUDY OBJECTIVES

The overall objective of the study has been to establish programmatic benefits to payloads which can result from the routine use of EVA. More detailed study objectives can be summarized as follows.

- Identify uses of EVA which significantly reduce payload costs.
- Compare technical and economic characteristics of selected payloads which are automated, teleoperator, or EVA-design oriented.
- Determine the amount of the cost savings attributable to EVA-oriented payload design and extrapolated to the NASA Payload Model.
- Develop a costing methodology for further NASA use.

The preliminary systems analysis phase of the study accomplished the first listed objective. It identified EVA applications that promise to lead to significant reductions in the costs of Shuttle payload development, fabrication and/or operation. In the second study phase, the remaining three objectives were accomplished. The study identified significant influences on payload design, integration, and operations brought about by the availability of a routine EVA capability and determined the associated cost benefits. These savings were projected to the entire NASA Payload Model; and NASA has been provided with the costing methodology employed in the study to permit recomputation of study results, if desired, based on differing assumptions or input data.

STUDY SCOPE

The study compared development, fabrication, and operations costs of representative baseline payloads to the costs of those payloads adapted for EVA operations. The baseline payload definitions are those currently endorsed by the appropriate project offices or found in standard reference data such as

the Shuttle System Payload Descriptions documentation. The EVA-oriented concepts developed in this study were derived from these baseline concepts and maintain mission and program objectives as well as basic configurations. This permits isolation of cost saving factors associated specifically with incorporation of EVA in a variety of payload designs and operations; e.g., benefits of EVA applied to a low-cost (modular) design compared to the benefits of EVA applied to current design spacecraft.

Results of prior studies relating to the desirability of on-orbit maintenance were accepted. This study examined the relative cost-effectiveness of EVA maintenance compared with automated maintenance. Maintenance areas examined included scheduled, unscheduled, and contingency.

The study scope included all aspects of payload design and operations but did not include assessments of STS-related costs associated with providing EVA capability. Thus, cost reductions and additions associated with payloads, such as elimination of automated electromechanical devices or provision of a payload EVA work station, are determined; whereas costs related to EVA suits, mobility aids, and similar STS-provided equipment (whether charged to the payload weight allowance or not) are not considered. The study did define requirements imposed upon such STS equipment by cost-effective EVA applications. Such requirements include desired response time, mobility, force/torque application, access and unique equipment.

BACKGROUND

EVA has been thoroughly demonstrated in Apollo and Skylab missions as a valuable tool and viable alternative to automated functions in routine mission operations, support to scientific experiments, and for planned or contingency maintenance and repair activities. Given a manned mission, the use of EVA for lunar exploration and scientific equipment deployment as conducted on Apollo missions was clearly more cost effective, reliable, and versatile than the automated Surveyor and Lunokhod type of operations. Automated alternatives to EVA for film cassette removal on Apollo "J" missions were rejected on the basis of cost and technical risk. Applications of EVA on the three Skylab manned missions ranged from the planned design solution of ATM film cassette exchange to major repair activities such as solar panel release.

Shuttle era payloads, including Spacelab and automated spacecraft which are flown on the orbiter can take advantage of manned operations including EVA. The NASA space program has been directed toward lower cost development of payloads and operations via utilization of the Space Shuttle and low cost systems. Low cost criteria will increasingly be applied to future program developments, and should include cost savings derived from planned application of EVA. This study provides visibility on EVA advantages and will hopefully encourage adoption of EVA-oriented designs by present and future program managers.

SUMMARY OF STUDY RESULTS

This study activity began with four stated objectives. Results of the study as reported in this final report have met these objectives and provided other results in the following manner.

1. *Identify uses of EVA which significantly reduce payload costs.*

The study identified 61 potential EVA applications--44 of which were Routine Operations; i.e., applied at some point in the mission cycle of every payload. Detailed design and cost data on mechanized elements resulted typically in Net EVA Savings of $75K to $150K for each such manual alternative. Conservatively, cost savings were only accumulated for 21 out of the total of 44 routine applications for which technical assurance and credible cost data could be provided.

2. *Compare Technical and Economic Characteristics of Selected Payloads--Automated, Teleoperator, or EVA Design Oriented*

Thirteen representative payloads were analyzed in the study. Baseline (automated) modes of operation were evaluated and compared to EVA modes. In all cases, EVA presented design simplification and lower costs. Gross and net savings attributed to EVA for DDT&E and first unit costs averaged $2.5 million for automated spacecraft and $8.9 million for sortie payloads.

3. *Determine the amount of these savings and extrapolate to the NASA payload model.*

The thirteen representative payload programs were extrapolated to a total of 74 programs compatible with EVA applications. These 74 programs require 249 flight units on a payload schedule compatible with the "572" Flight Model. Using appropriate complexity and learning factors, net EVA savings were extrapolated to over $551M for NASA and U.S. civil payloads for routine operations. Adding DoD and ESRO payloads increases the net estimated savings to $776M.

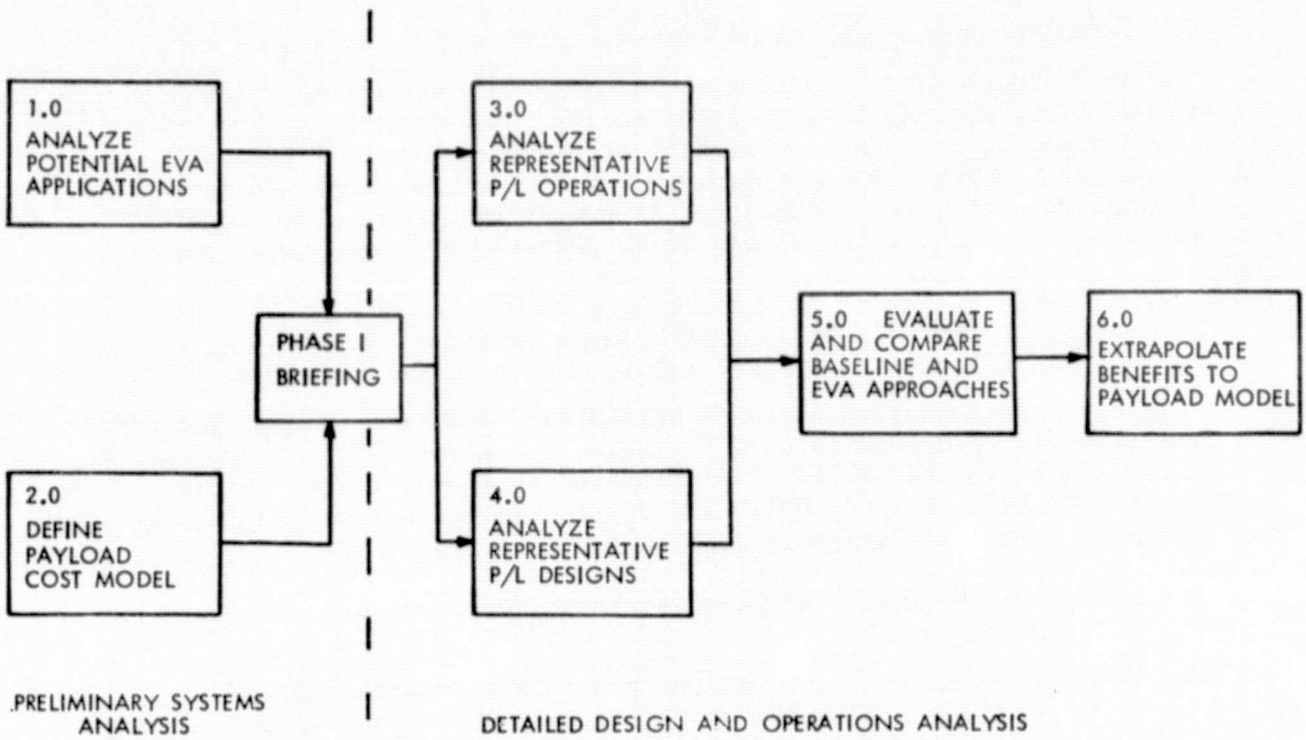
4. *Evaluate and Compare Automated Versus EVA Task Times.*

Credible task-time data were applied to the payload operations to derive integrated, comparative timelines. With EVA, routine preparation timelines were decreased in one case by 1.7 elapsed hours to a maximum increase of 1.3 hours--average 0.5 hour increase. EVA durations ranged from 1.5 hours to 6 hours--average 3.7. These activities require the following:

One-man EVA	11 payloads	One EVA cycle	9 payloads
Two-man EVA	2 payloads	Two EVA cycles	4 payloads
		Three EVA cycles	1 payload (on-orbit maintenance)

5. *Determine Maintenance and Contingency Cost Savings.*

Planned maintenance for a projected 13 payload programs (out of a possible 51 payload programs) indicated an estimated $168M savings due to elimination of automated servicing equipment. If all spacecraft designated "Reusable" (28 programs) are included, the potentially extrapolated cost savings of the EVA mode would be ∿$316M. EVA savings for contingency problems of payloads were based on transport and equipment costs only. While the historical data do not necessarily establish expected failure rates for Shuttle payloads, the failure information was examined to select only credible analogs. The total estimated EVA potential for savings was about $1.9 billion.



Study Task Logic

STUDY TASKS AND REPORT STRUCTURE

A two-phase study approach was planned consisting of a preliminary systems analysis phase followed by a detailed design and operations phase. A total of six tasks were conducted in the study. The accompanying figure is a simplified study logic diagram. The first two tasks, Analyze Potential EVA Applications (1.0) and Define Payload Cost Model (2.0), were reviewed at the Phase 1 briefing held at NASA Ames Research Center on 11 October 1974. Task 3.0, Analyze Representative Payload Operations, and Task 4.0, Analyze Representative Payload Designs, investigated in more detail the promising EVA applications uncovered in the preliminary system analysis phase of the study. They developed the technical data regarding 13 representative payloads that permitted the comparative cost analysis performed in Task 5.0, Evaluate and Compare Baseline and EVA Approaches. Task 6.0, Extrapolate Benefits to Payload Model, extrapolated the results of Task 5.0 to the NASA payload model and summarized key payload effects as well as developments required to permit realization of the projected benefits.

Technical results of the study are reported in this volume, which is organized into five sections as follows.

SECTION I. PRELIMINARY SYSTEMS ANALYSIS

The key issues dealt with in this section were the selection of candidate EVA concepts for payload design and operation and their assessment for "high-payoff" benefits.

The section first describes the rationale for grouping NASA payloads and for selecting representative payloads from each group. Thirteen representative payloads were selected and used for initial evaluation as well as for the later detailed analyses. The Preliminary systems analyses identified a total of four mission classes. Each segment of the missions was examined to establish a set of EVA activities or applications that could be applied to a payload. Each representative payload was reviewed for compatibility with these applications or to uncover new concepts. The result of the initial listing and the iteration was a total listing of 61 EVA applications for further evaluation. By applying simplified cost factors to these candidates, over $300M was identified as potential benefits based on a range of from 19 to 48 applications out of the 61 total possible for the various payloads.

SECTION II. DESIGN AND OPERATIONS ANALYSIS

Before analyzing each representative payload in depth, a series of "building blocks", or elements common to more than one payload, was analyzed. For example, antenna deployment mechanisms are used by many payloads. The detailed design characteristics for both a baseline and an EVA-operable type need only be evaluated and costed once, then applied as pertinent to representative payloads. A key issue in this analysis was to secure or develop credible data to support "bottom-up" cross-checks on the overall cost analysis. Other data developed to support payloads analysis includes basic design criteria for orbiter payloads, orbiter supporting provisions, and orbiter mission timelines affecting payloads.

Generic mission activity sequences were also produced for EVA applications common to more than one payload. These serve as a reference to the later detailed representative payload task/time analyses. The significant result in analyzing building blocks of payload design and operations was that automated mechanisms are complex and costly based on highly credible data, compared to EVA manual designs developed in the study.

Two operations issues studied programmatically are discussed in this section. They are contingency analysis and planned maintenance. The contingency analysis was based on historical data, while the maintenance operations compared EVA to automated modes.

SECTION III. REPRESENTATIVE PAYLOADS ANALYSIS

This section contains the results of the design and operations analyses of the baseline and EVA-oriented concepts of the 13 representative payloads. Data for payload flight and support hardware are organized into non-recurring and recurring categories for subsequent costing. The analysis is based on the data contained in Section II on payload design and operations elements, and includes for each payload, design data, overall activity sequences, and integrated mission timelines for baseline and EVA-oriented concepts.

A key issue in this section was to identify baseline design characteristics to a sufficiently low level to allow discrimination of EVA alternative designs. To accomplish this, detailed data was compiled (or developed when necessary) to a WBS level 6 or 7 whenever an EVA alternative to the baseline design was identified. Detailed timeline development was supported by baseline payload source data and further developed from building block data and payload analysis. For all payloads analyzed, EVA reduced cost and complexity with little operational impact.

SECTION IV. COMPARATIVE ANALYSIS AND PROGRAM EXTRAPOLATION

This section describes: (1) determination of representative payloads EVA cost savings, (2) development of study payload/traffic model, and (3) methodology of extrapolating representative payload EVA cost savings to the model.

Key issues dealt with in this section are: (1) correlating of payload technical characteristics with traffic data so as to correctly assign DDT&E and unit costs, and (2) assigning complexity factors relating each payload in a group to its representative payload to ensure reasonable comparable cost. Total results of savings for EVA-oriented NASA payloads (routine operations only) was about \$550M. This total reached \$776M when simple extrapolations were made to DoD spacecraft and non-NASA/non-DoD sortie payloads.

SECTION V. SPECIAL ISSUES

Special programmatic and technical topics were examined during the course of the study. These analyses were not related to the representative payload analyses specifically. The special topics were examined when it became clear that they had a bearing on the credibility of the applications of EVA which were key to achieving projected benefits. These topics are man-rating, contamination, EVA provisions, technology, training, and cost factors.

The accompanying table cross references the study task breakdown described earlier with the content of each of the volumes of the final report.

Document	Task No. 1.0	2.0	3.0	4.0	5.0	6.0
Vol. 1 - Executive Summary						
Summaries	X	X	X	X	X	X
Vol. 2 - Technical Analyses						
Section I	X					
Section II			X	X		
Section III			X	X		
Section IV		X			X	X
Section V					X	
Vol. 3 - Cost Data		X			X	

1. PRELIMINARY SYSTEMS ANALYSIS

This section describes the preliminary systems analysis, including a summary description of the representative payloads and an explanation of the rationale for their selection. The data presented reflect original source data for baseline payloads. These data were amplified by analyses conducted in order to provide the system definition required for development of EVA approaches. In addition the section describes the selection and evaluation of a range of EVA applications and conclusions regarding their potential for high payoff benefits.

1.1 REPRESENTATIVE PAYLOAD SELECTION

The initial effort in the selection of the representative payloads was to categorize all the payloads found in the payload reference documentation into appropriate groups. Once the appropriate groups were established, representative payloads were then selected based on several important criteria. A major objective of the initial analysis was to select groups such that data concerning EVA benefits for the representative payloads could readily be extrapolated to all other payloads in the group. The full range of factors which are necessary to understand the grouping requirements are discussed in detail below. A secondary objective in grouping of spacecraft was to ensure that major characteristics of any individual spacecraft would be found in at least one representative payload.

Since the sortie payloads are distinctly different from automated spacecraft at program and mission operational levels, and in typical hardware, separate grouping analyses were conducted for sortie and automated payloads.

1.1.1 Grouping Analysis for Automated Spacecraft

Four principal categories of representative payload groups were established. The first consists of all automated payloads delivered directly to their operational orbits by the Shuttle without using a large upper stage (IUS or Tug). This category includes spacecraft such as EOS that employ small propulsion packages to provide additional boost as well as spacecraft which are delivered directly to their operational orbit by Shuttle. The second category consists of automated spacecraft requiring an upper stage to attain their operational orbits. Planetary and lunar payloads constitute a separate category. These three categories differ primarily in the operational complexity of providing EVA capability during various mission phases. Sortie (Spacelab) payloads constitute the fourth category considered in the study.

Within each category of automated payloads, distinctions were made regarding the fundamental design concept and whether the payload is planned for recovery or to be expended.

The grouping process was started by classifying all spacecraft according to their design approach. Four basic groupings were selected consisting of Low Cost Reusable (LCR), Low Cost Expendable (LCE), Current Design Reusable (CDR), and Current Design Expendable (CDE). *Low cost* spacecraft are those which utilize common equipment and modular design and assembly. Consideration is given to reduced design reliability and qualification testing where permitted by the mission. These factors all affect potential EVA application in terms of greater ability to remove and replace modules, coupled with possibly greater need. While current design spacecraft do not reflect the above characteristics, they may be reusable. Reusable, as opposed to expendable, is an important characteristic to this study in terms of candidate EVA activities--obviously, the retrieval cycle can only apply to this class of spacecraft.

This classification scheme ensures that the derived EVA benefits can be accurately extrapolated from the representative payloads to any similarly classified payload in the NASA payload model on the basis of overall design and operations approach. A significant benefit of this grouping is that, where detailed design definitions for represented payloads do not now exist, cost savings can be projected on the basis of overall design philosophy. Assignment of spacecraft by class essentially follows NASA designations[(1)] with some modification based on current in-house studies.

Because of different operational activities with Interim Upper Stage (IUS) or Tug-delivered payloads, groups were further separated into *upper stage required* and *no upper stage required*. For example, preparation of payloads for Tug delivery may not permit early appendage deployment due to g-loads or, if deployed, would reflect possible higher structural weight (and costs)--therefore warranting evaluation of the separate classes. Also, periodic maintenance of spacecraft retrieved by a Tug would require inclusion of higher transportation costs than at Shuttle orbit. Although planetary and lunar payloads are defined as LCE or CDE, it was determined that a separate planetary category would be needed due to different economic considerations. This allows evaluation of such special factors as RTG's, electrical propulsion stages, unique economic considerations, and the emphasis on planetary payload deliveries of ensuring a successful mission before departing from the Shuttle. Table 1-1 lists all of the study's automated spacecraft by group.

1.1.2 Sortie Payload Grouping

Grouping of sortie payloads could not be accomplished using the automated spacecraft approach. Initially, laboratory-only payloads were eliminated from candidate groupings per RFP direction (and because of probability of small EVA benefit). The remaining payloads were examined for orbital operations, support function characteristics, and numbers and types of mechanisms. A matrix of commonality established the fact that three groups would be required to adequately cover all potentially significant EVA applications. The groups are defined as follows:

[(1)] NASA TMX-64751 (Rev. 2), "The October 1973 Space Shuttle Traffic Model," by Shuttle Utilization Planning Office, Program Development, January 1974, MSFC.

Table 1-1. Automated Payload Groups

Group	SSPD ID	Name	Group	SSPD ID	Name
NO UPPER STAGE REQUIRED					
LCR	EO-08	Earth Observations Satellite	CDR (Cont)	HE-03	Extended X-Ray Survey
	-61	Earth Resources Survey Operational Satellite		HE-05	High Latitude Cosmic Ray Survey
	LS-02	Biomedical Experiment Scientific Satellite		HE-08	Large High Energy Observatory A(Gamma Ray)
	OP-05	Vector Magnetometer Satellite		HE-07	Large High Energy Observatory C(Nuclear Calorimeter)
	-51	Global Earth and Ocean Monitor System		HE-10	Small High Energy Satellite
LCE	AP-04	Gravity and Relativity Satellite-LEO		HE-12	Cosmic Ray Laboratory
	EO-10	Applications Explorer (C and D)		SO-02	Large Solar Obsevatory
CDR	AS-01	Large Space Telescope		SO-03	Solar Maximum Mission
	AS-03	Cosmic Background Explorer		ST-01	Long Duration Exposure Facility
	HE-01	Large X-Ray Telescope Facility	CDE	OP-03	Mini LAGEOS
	HE-11	Large High Energy Observatory D(1.2m X-ray Telescope)			
UPPER STAGE REQUIRED					
LCR	OP-06	Magnetic Field Monitor Satellite	CDR (Cont)	AP-02	Medium Altitude Explorer
	EO-56	Environmental Monitoring Satellite		AP-05	Environmental Perturbation Satellite - Mission A
	CN-54	Disaster Warning Satellite		AP-07	Environmental Perturbation Satellite - Mission B
LCE	AI-03	High Altitude Explorer		EO-09	Synchronous Earth Observatory Satellite
	AP-06	Gravity and Relativity Satellite - Solar		EO-12	TIROS "O"
	EO-07	Advanced Synchronous Meteorological Satellite		EO-57	Foreign Synchronous Meteorological Satellite
	EO-10	Applications Explorer (A,B and E)		EO-58	Geosynchronous Operational Meoteorological Satellite
	CN-52	U.S. DOMSAT "A"		EO-59	Geosynchronous Earth Resources Satellite
	CN-55	Traffic Management Satellite		EO-62	Foreign Synchronous Earth Resources Satellite
	CN-59	Communications R&D/Prototype Satellite		CN-51	INTELSAT
CDR	CN-58	U.S. DOMSAT "C"		CN-53	U.S. DOMSAT "B"
	AS-02	Extra Coronal Lyman Alpha Explorer		CN-56	Foreign Communications Satellite A
	AS-05	Advanced Radio Explorer		CN-60	Foreign Communications Satellite B
	AS-16	Large Radio Observatory Array (LROA)	CDE	OP-01	GEOPAUSE
	AP-01	Upper Atmosphere Explorer		AP-08	Heliocentric and Interstellar Spacecraft
PLA	PL-12	Mariner Jupiter Orbiter	PLA (Cont)	PL-13	Pioneer Jupiter Probe
	PL-01	Mars Surface Sample Return		PL-15	Uranus Probe/Neptune Flyby
	PL-02	Mars Satellite Sample Return		PL-19	Halley Comet Flyby
	PL-03	Pioneer Venus Multiprobe		PL-20	Asteroid Rendezvous
	PL-07	Venus Orbital Imaging Radar		LU-02	Lunar Orbiter
	PL-08	Venus Buoyancy Probe		LU-03	Lunar Rover
	PL-09	Mercury Orbiter		LU-04	Lunar Halo Satellite
	PL-10	Venus Large Lander		LU-05	Lunar Sample Return

Group 1. Payloads containing pointing, pallet-mounted sensors (sortie observatories).

Group 2. Payloads containing sensors mounted on extensible booms and platforms.

Group 3. Payloads containing a variety of pallet-mounted sensors and mechanisms.

It also became apparent that some Spacelab module airlock operations using extendible devices could realize design simplification and cost savings through application of EVA. Therefore, payloads of this type constitute a fourth group. The sortie payload groups thus defined are listed in Table 1-2.

Table 1-2. Sortie Payload Groups

Type	SSPD ID	Name
		Group I Sortie Observations
P	AS-01	1.5m Cryo-Cooled IR Telescope - SIRTF
	AS-03	Deep Sky UV Survey Telescope
	AS-04	1m Diffraction Limited UV Optical Telescope
	AS-06	Calibration of Astronomical Fluxes
	AS-07	Cometary Simulation
	AS-10	Advanced XUV Telescope
	AS-11	Polarimetric Experiments
	AS-12	Meteoroid Simulation
	AS-14	1m Uncooled IR Telescope
	AS-15	3m Ambient Temperature IR Telescope
	AS-19	Selected Area Deep Sky Survey Telescope
	AS-20	2.5m Cryo-Cooled IR Telescope
	AS-31	Combined AS-01, -03, -04, and -05S
	AS-50	Combined UV/XUV Measurements (AS-04, -10S)
	AS-51	Combined IR Payload (AS-01, -15S)
	AS-54	Combined UV Payload (AS-03, -04S)
	HE-11	X-Ray Angular Structure
	HE-12	High Inclination Cosmic Ray Survey
	HE-13	X-Ray/Gamma Ray Pallet
	HE-14	Gamma Ray Pallet
	HE-16	High Energy Gamma-Ray Survey
	HE-17	High Energy Cosmic Ray Study
	HE-18	Gamma-Ray Photometric Studies
	HE-19	Low Energy X-Ray Telescope
	HE-20	High Resolution X-Ray Telescope
	SO-01	Dedicated Solar Sortie Mission (DSSM)
	SO-11	Solar Fine Pointing Payload
P	SO-12	ATM Spacelab

Note: Several of the SSPD payloads are not included - 25 are small carry-on and eight are laboratory operations only.
Type: P=Pallet M=Module

Type	SSPD ID	Name
		Group II Boom Extended Sensors
P + M	AP-06	Atmospheric, Magnetospheric and Plasmas in Space
P	AS-09	30-Meter IR Interferometer
P	AS-18	1.5km IR Interferometer
P + M	LS-04	Free Flying Teleoperator
		Group III Assorted Pallet Mounted Mechanisms
P	ST-23	ATL Payload No. 5 (Pallet)
P	HE-15	Magnetic Spectrometer
P + M	OP-02	Multifrequency Radar Land Imagery
P + M	OP-03	Multifrequency Dual Polarized Microwave Radiometry
P	OP-04	Microwave Scatterometer
P + M	OP-05	Multispectral Scanning Imagery
P + M	OP-06	Combined Laser Experiment
P + M	SP-12	SPA No. 12 - Automated Furnace (F^1+C^1
P + M	SP-13	SPA No. 13 - Automated Levitation (L^1 C^1)
P + M	SP-14	SPA No. 14 - Manned and Automated (B+G+C+F^1+L^1)
P + M	SP-15	SPA No. 15 - Automated Furnace/Levitation (F^1+L^1+C^1)
P + M	SP-16	SPA No. 16 - Biological/General (Manned) (B+G+C)
P + M	SI-19	SPA No. 19 - Biological and Automated (B+C+F^1+L^1)
P + M	ST-21	ATL Payload No. 2 (Module + Pallet)
P + M	ST-22	ATL Payload No. 3 (Module + Pallet)
P	EO-05	Shuttle Imaging Microwave System (SIMS)
P + M	CN-04	Terestrial Sources of Noise and Interference
P + M	CN-05	Laser Communication Experiments
P + M	CN-06	Communication Relay Tests
P	CN-07	Large Reflector Deployment
P + M	CN-08	Open Traveling Wave Tubes
P + M	CN-11	S.T.A.R.S. and P.A.D.S. Experimentation
P + M	CN-12	Interferometric Navigation and Surveillance Technique
		Group IV Airlock Operations
P + M	ST-04	Wall-less Chemistry and Mol. Beam Facility (No. 1)
M	ST-06	Fluid Physics and Heat Transfer Facility (No. 3)

1.1.3 Representative Payload Selection

Selection of representative payloads for each group met the objectives stated at the beginning of this section and, as far as possible, met the following criteria.

1. Design and operations data available to a reasonable depth.
2. Significant SD experience on the payload.
3. Suitability of candidate for extrapolation of characteristics to other spacecraft.
4. Existence of a large number of EVA applications.

In order to evaluate the latter two selection criteria, an initial survey was made of spacecraft physical characteristics. Table 1-3 shows a summary of this survey by group for the automated spacecraft. Although characteristics are distributed across groups, a degree of commonality is reflected--especially in the detailed data which cannot easily be presented here. SSPD Level B[(1)] data (a prime source of information on technical characteristics) are currently lacking for about 30 percent of the automated payloads; therefore, characteristics determined reflect several other sources.

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(1) Summarized NASA Payload Descriptions - Preliminary (Sortie and Automated), NAS8-29462, Shuttle System Payload Description (SSPD), dated July 1974.

Table 1-3. Automated Payload Characteristics

CHARACTERISTIC	PAYLOAD GROUP								
	NO UPPER STAGE				UPPER STAGE				PLANETARY
	LCR	LCE	CDR	CDE	LCR	LCE	CDR	CDE	
CONTAM. SHIELDS	X	X	X	X	X	X	X	X	X
BOOST-ENTRY LATCHES	X	X	X	X	X	X	X	X	X
DEPLOYABLE ANTENNAS			X		X	X	X		X
DEPLOY. SOLAR ARRAY	X	X	X		X	X	X	X	X
INSTRUMENT BOOMS	X				X	X	X		X
EXTEND. SUNSHADE			X						
TWO-WAY UMBILICAL	X		X		X		X		
DOCKING MECHANISM	X								
PLANNED MAINTENANCE	X		X				X		
CRYOGENICS		X							
RTG'S									X
ELECTRIC PROPULSION									X

Sortie payloads were evaluated in a similar manner, as summarized in Table 1-4. The review resulted in selection of payloads that generally meet the criteria satisfactorily. All of the selected representative spacecraft/payloads are listed in Table 1-5. Each payload represents a set of payloads having similar EVA applicability; each set, however, differs significantly from other sets in one or more areas of EVA applicability. Table 1-6 summarizes mission requirements discussed previously for the 13 selected representative payloads.

Table 1-4. Sortie Payload Characteristics

Typical Characteristics	Sortie Payload Group			
	Gimbal Mounted Sensors	Extensible Sensors	Pallet Installed Mechanisms	Airlock Operations
Total Number of Payloads in Group	28	4	23	2
Rotatable/Gimbaled Telescopes (Sensors)	27	2	6	-
Deployable/Extend. Devices	5	3	14	2
Film Used	8	-	8	2
Subsatellite	-	2	1	-
Cryogenics Required	9	2	4	-
Fixed Pallet Equipment	-	-	8	-

Table 1-5. Representative Payloads

GROUP	SSPD NO.	NAME
		NO UPPER STS STAGE (TUG)
LCR	EO-08	EARTH OBSERVATORY SATELLITE (EOS)
LCE	AP-04	GRAVITY AND RELATIVITY SATELLITE (GRS)
CDR	AS-01	LARGE SPACE TELESCOPE (LST)
CDE	OP-03	MINILAGEOS (MIN)
		UPPER STAGE (TUG) REQUIRED
LCR	OP-06	MAGNETIC FIELD MONITOR SATELLITE (MFM)
LCE	AP-03	HIGH-ALTITUDE EXPLORER CLASS (HAE)
CDR	CN-58	U.S. DOMSAT "C" (DOM)
CDE	OP-01	GEOPAUSE (GEO)
		PLANETARY
	PL-12	MARINER JUPITER ORBITER (MJO)
		SORTIE
1	AS-01	1.5M IR TELESCOPE (SIRTF)
2	AP-06	ATMOSPHERIC, MAGNETOSPHERIC AND PLASMAS IN SPACE (AMPS)
3	ST-23	ADVANCED TECHNOLOGY LAB (ATL)
4	ST-04	PHYSICS AND CHEMISTRY FACILITY (PCF)

Table 1-6. Representative Payload Mission Requirements

Payload Classes	LEO				HEO					SORTIE			
	EOS	GRS	LST	MIN	MFM	HAE	DOM	GEO	MJO	SIRT	AMPS	ATL	PCF
Direct Placement	X	X	X	X									
Orbiter + Upper Stage					X	X	X	X	X				
Sortie Missions										X	X	X	X
Retrieval Missions	X		X		X		X						
Expendable		X		X		X		X	X				
On-Orbit Maintenance	X		X							(As desired)			
Low Cost Design	X	X			X	X			X				
Current Design			X	X			X	X	X				

1.2 EVA APPLICATIONS

The analysis of potential EVA applications for each of the representative payloads proceeded in two phases. The first phase identified a series of top-level on-orbit operations with a potential for EVA activities which were then established and analyzed in further detail for each of the representative payloads. The activities were reviewed for commonality, and compiled as a matrix of candidate EVA applications versus representative payloads. This matrix became the basis for further detailed analyses of EVA applications in the second phase of the study.

1.2.1 Mission Logic Analysis

Four classes of missions were established which cover all basic Shuttle-related operations: sortie, spacecraft delivery, maintenance, and retrieval.

For sortie missions, the major on-orbit activities include preparation for experiments, the performance of experiments and, finally, the shutdown of experiment equipment and storage in preparation for orbiter return, Figure 1-1. During any on-orbit phase, contingency operations may be required to accomplish experiment objectives or avoid loss of experiment equipment. Typical activities with EVA potential applications are listed below each of the major blocks. Most of these potential EVA activities involve manual operations in lieu of automated electromechanical devices. Other activities involve operations which allow simplification of original plans or provide flexibility in the on-orbit experiment program. Examples of this type are mounting of instruments, loading of film, and inspection of exterior exposed samples. Other EVA activities could add to sortie mission program effectiveness by cleaning sensors and performing various contingency operations. Contingency operations might be entered at any point during the mission and would exit to normal operations.

A major class of Shuttle missions is that of delivery of automated spacecraft to orbit. Operations performed on-orbit for this class of mission are shown in Figure 1-2. Among the activities in normal delivery mission operations are functions with potential EVA involvement for replacing or simplifying automated electromechanical devices which otherwise would be custom designed and manufactured for the application.

Other functions in which EVA operations provide benefits include: (1) loading cryogenic fluids; (2) installing instruments which would better be protected in orbiter cabin or Spacelab environment during ascent; (3) installing specially shielded RTG's; (4) removing safety devices such as pyrotechnic shorting plugs; (5) providing general *on-the-spot* pre-separation inspection of the spacecraft; (6) loading of films into spacecraft data gathering devices; and (7) making or breaking spacecraft-to-Shuttle connections.

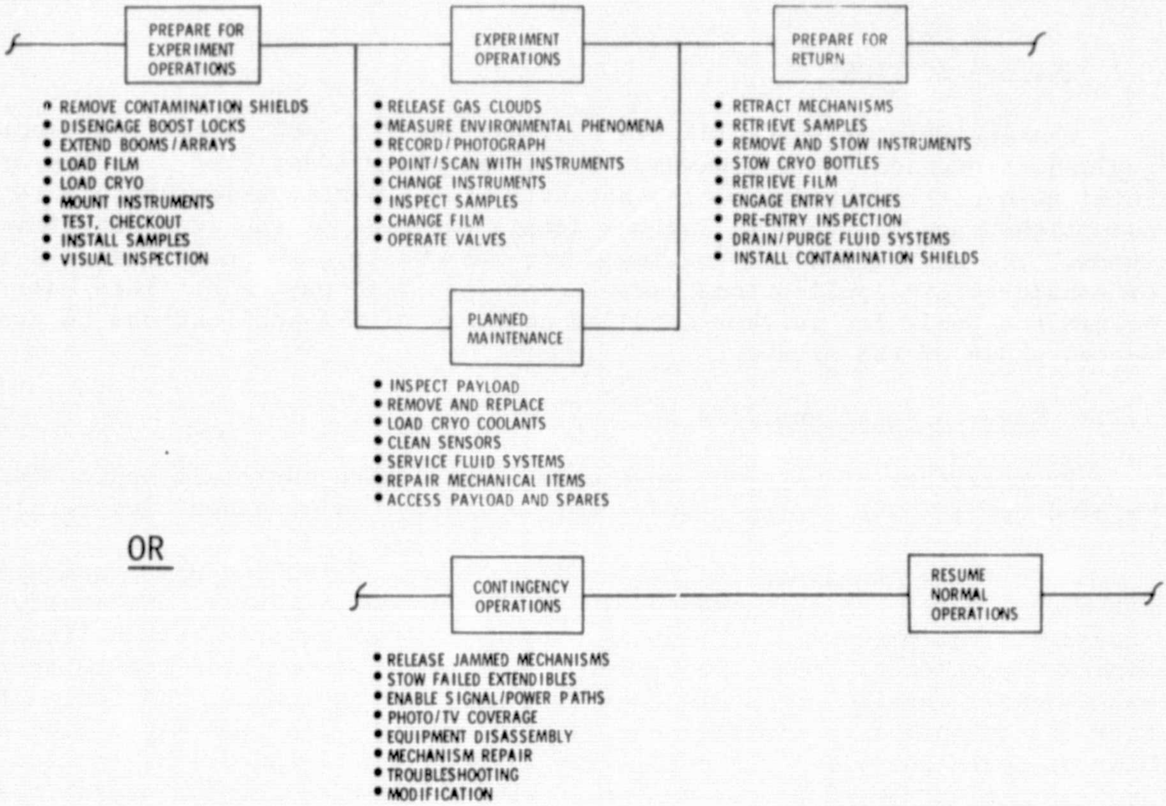

Figure 1-1. Sortie Mission Flow/EVA Applications

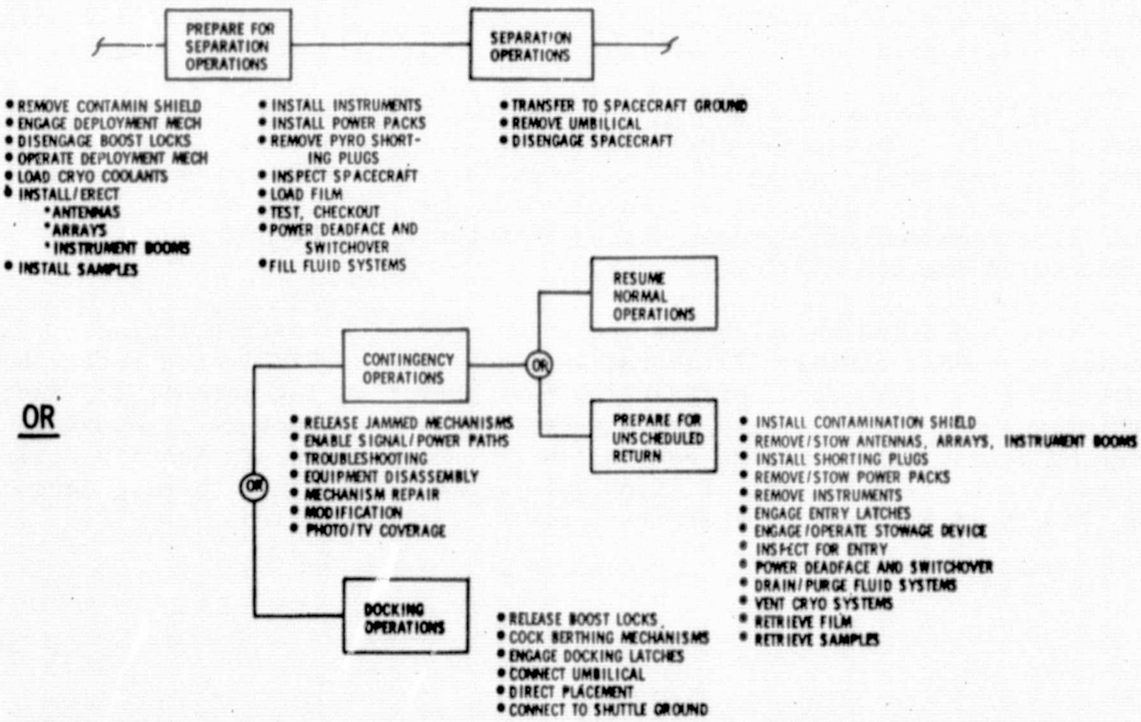

Figure 1-2. Spacecraft Delivery Mission Flow/EVA Applications

The top-level operational blocks include a potential for contingency situations. The EVA functions identified in this area include both contingency activities (i.e., those activities such as releasing jammed mechanisms, restoring the spacecraft to an operating mode) and routine activities which are performed on an unscheduled basis so as to return a failed spacecraft to earth.

Figure 1-3 illustrates on-orbit operations required for a maintenance or retrieval mission of an automated spacecraft which were combined because of commonality. The major areas for a maintenance mission include docking, maintenance, and separation. For a retrieval mission, the operations are docking and prepare for return. Again, for contingency situations, either contingency activities or unscheduled routine activities may be performed.

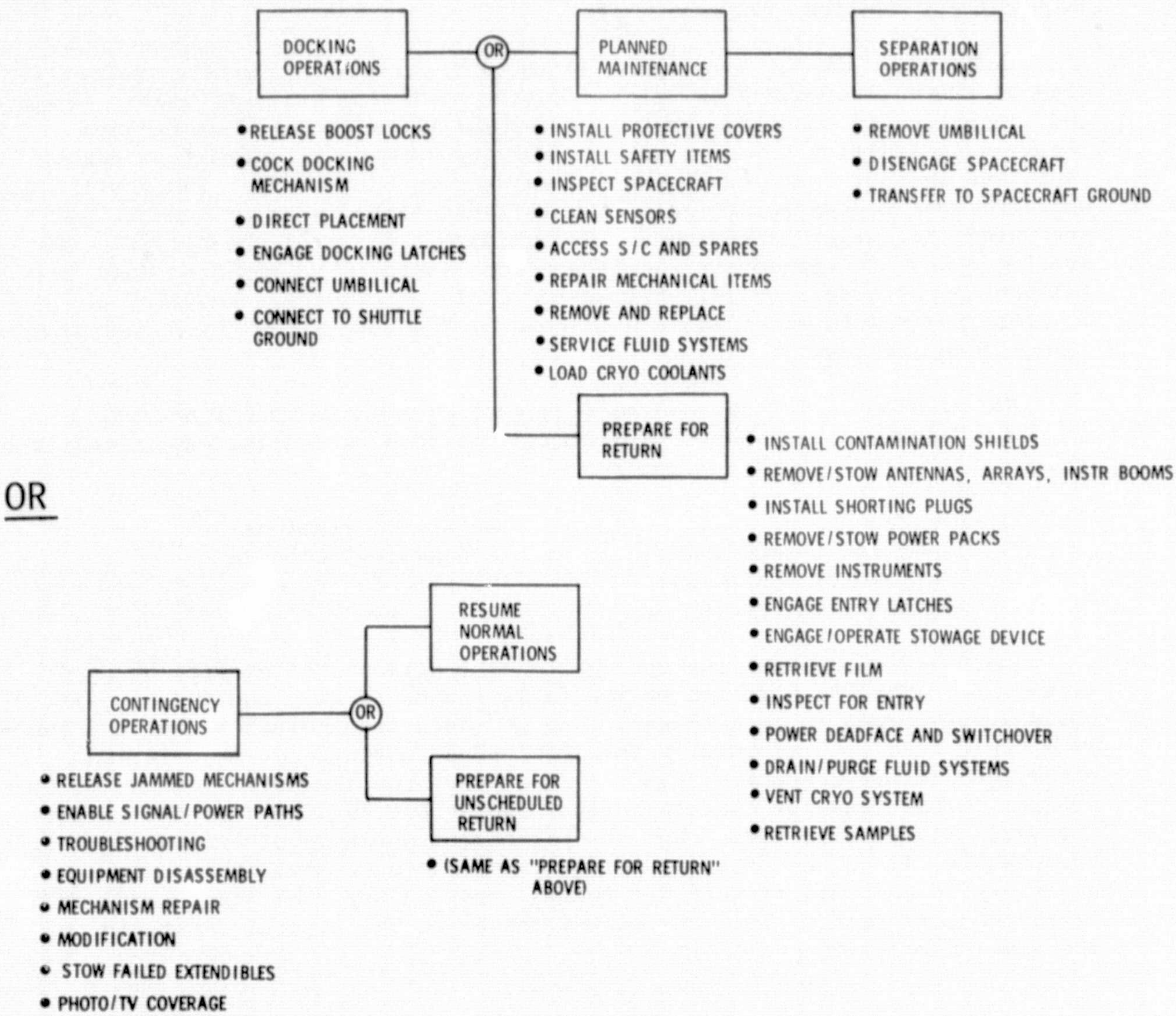

Figure 1-3. Spacecraft Maintenance Flow/EVA Applications

Under docking operations, the proposed EVA activities involve preparing the orbiter-carried docking provisions to mate with the spacecraft being retrieved and supporting the docking operation. Retrieval can be for performing on-orbit servicing/maintenance operations or for returning the spacecraft to earth. The docking provisions will require restraint during ascent. Such restraints may be manually disconnected by the EVA crew. At the same time, mechanical contact actuated devices which will capture the spacecraft static fittings could be manually set for the capture operation.

EVA activities envisioned for the docking phase operations include providing EVA monitoring and direction of the orbiter maneuvers required to facilitate capture of the spacecraft by the docking mechanism. The location of the EVA crewman in a position near the spacecraft would augment the orbiter cabin crew vision and the orbiter-supplied sensor capability to result in more accurate and reliable docking operations. After the mechanical latches have been tripped in the docking operation, EVA could be utilized to manually secure the retention latches.

Under the Planned Maintenance block, EVA activities include installation of protective covers on optical surfaces, installation of safety items, and inspection of the spacecraft to determine the extent of maintenance required in addition to the planned servicing. Many EVA operations can be performed in spacecraft servicing and maintenance functions. These will vary with the type of spacecraft being maintained and the types of sensors and subsystems requiring maintenance. In all cases, EVA could be utilized to provide access to spacecraft subsystems/components to be replaced, and to release spares from storage. Remove-and-replace activities required to complete the maintenance also can be done by EVA rather than by an automated/teleoperator system.

The mission logic resulted in redundant mission functions occurring from one diagram to another. Seven unique mission categories were established and are listed below:

1. Pre-operations
2. Experiment operations
3. Contingency operations
4. Separate spacecraft
5. Docking operations
6. Planned maintenance
7. Prepare for return

Table 1-7 summarizes the occurrence of functional categories by type of mission. The "N" notation on the table indicates that the function is normally performed on each flight. The "C" notation indicates that the function would only be performed in the event of a contingency--that is, an unforeseen occurrence which requires departure from the normal course of events. Other than for the contingency operations on line 3 of the table, however, this does not mean that the procedures would be other than normal. For example, if in the process of retrieving a spacecraft, it becomes necessary to separate from it due to some contingency, the separation would likely be performed in the same normal manner as the initial separation of the same spacecraft.

Table 1-7. Functional Operations by Mission

FUNCTIONAL CATEGORY	TYPE OF MISSION			
	SORTIE	SPACECRAFT DELIVERY	SPACECRAFT MAINTENANCE	SPACECRAFT RETRIEVAL
1. PRE-OPERATIONS	N	N		
2. EXPERIMENT OPERATIONS	N			
3. CONTINGENCY OPS.	C	C	C	C
4. SEPARATE SPACECRAFT		N/C	N/C	C
5. DOCKING OPERATIONS		C	N	N
6. PLANNED MAINTENANCE	N		N	
7. PREPARE FOR RETURN	N	C	C	N

In some cases, the various categories of EVA applications apply to payload classes uniquely. For example, the generic EVA applications identified for experiment operations would apply exclusively to sortie payloads as automated spacecraft experiments do not begin until after separation from the orbiter. Planned maintenance does not, of course, apply to expendable spacecraft, nor do separation and docking apply to sortie payloads.

1.2.2 Payload Function Analysis

All of the candidate EVA applications from the mission flow analysis, eliminating the redundancy, were listed by functional category. Each representative payload design concept was then evaluated to establish whether or not EVA could reasonably be expected to perform the function. A complete listing of candidate EVA applications versus representative payloads is presented in Table 1-8.

As would be expected, the greater number of potential applications occurs in the reusable payload classifications. Each potential EVA application was examined in greater detail during Phase 2 of the study. However, the initial analysis examined potential EVA applications for each payload/mission, such as a Mariner Jupiter Orbiter (MJO) spacecraft delivery mission. This mission is similar to other deliveries, but has some additional unique characteristics. The first function analyzed is that of EVA-assisted removal of a shroud which encloses the entire MJO spacecraft forward of the Centaur propulsion stage. The EVA activity could involve manual unlatching and opening of the metallic shroud which would be attached to the orbiter bay structure. Exterior EVA work stations would be required and are illustrated conceptually in Figure 1-4.

A special requirement for the MJO payload is in the handling of the radioisotope thermoelectric generator (RTG) package for supplying spacecraft power during its interplanetary operations. This unit requires cooling while it is within the orbiter cargo bay. Removal of a cooling jacket via EVA is illustrated in the upper sketch of the figure. A suitable work station would be provided on the interior of the contamination shield as shown, to allow access to the cooling jacket. An additional benefit for EVA in this application is that EVA could readily be used to re-install the cooling jacket in the event of delay in release of the MJO or if mission abort and return to the ground is required.

Table 1-8. Candidate EVA Applications Versus Representative Payloads

Spacecraft	DIRECT PLACEMENT				ORBITER + TUG PLACEMENT					SHUTTLE PAYLOADS				
Spacecraft	EOS	GRS	LST	MIN	MFN	HAE	DOM	GEO	MJO	IRT	ASP	ATL	PCF	
P/L Number / EVA Applications	EO-08	AP-04	AS-01	OP-03	OP-06	AP-03	CN-58	OP-01	PL-12	AS-01	AP-06	ST-23	ST-04	Remarks
1. PRE-OPERATIONS														Sortie or automated spacecraft
1.1 Remove contamination shields	X	X	X	X	X	X	X	X	X	X	X	X		
1.2 Disengage boost locks	X	X	X	X	X	X		X		X	X	X	X	Equipment or spacecraft
1.3 Install erect extend:														
.1 Antennas	X		X		X						X	X		
.2 Solar arrays	X	X	X		X									
.3 Instrument booms/sunshade	X	X	X		X					X	X	X	X	
.4 Mechanisms	X									X	X	X	X	
1.4 Engage RMS oper. depl. device	X	X	X	X										Crew assist, viewing or placement
1.5 Load film												X	X	
1.6 Load cryo coolants		LH_e								LH_e	LN_2			Install tank or operate valves/ connectors
1.7 Install instruments	X	X	X		X	X					X	X	X	
1.8 Test, checkout	X		X		X	X	X	X		X	X	X	X	Observe deployment, etc.
1.9 Install replace samples												X		
1.10 Visual inspection	X	X	X	X	X	X	X	X	X	X	X	X	X	
1.11 Remove pyro shorting plugs	X		X		X	X	X	X	X					
1.12 Power pack installation			X						X					Crew handling for RTG-type systems
1.13 Power deadface and switchover	X	X	X		X	X	X	X	X					
1.14 Fill fluid systems	X	X	X		X	X	X	X	X					
2. EXPERIMENT OPERATIONS														Sortie mode only
2.1 Launch canisters/gas clouds/ subsatellites											X	X		
2.2 Measure environ. phenomena											X	X	X	Unplanned/random sampling
2.3 Record photograph											X	X	X	
2.4 Point, scan with instruments												X	X	Normal hookup
2.5 Inspect samples												X		
2.6 Change film											X		X	
2.7 Operate valves										X	X	X	X	
2.8 Change instruments										X	X	X	X	
3. CONTINGENCY OPERATIONS														
3.1 Release operate jammed mechanisms	X	X	X		X					X	X	X	X	
3.2 Jettison/retract stow failed extendibles	X	X	X		X					X	X	X	X	
3.3 Enable/disable signal power paths	X	X	X		X	X	X			X	X	X	X	Cut cables, install jumpers, etc.
3.4 Photo TV coverage	X	X	X	X	X	X	X	X	X	X	X	X	X	
3.5 Equipment disassembly	X	X	X		X	X	X	X	X	X	X	X	X	
3.6 Mechanism repair	X	X	X		X	X	X	X	X	X	X	X	X	
3.7 Troubleshooting	X	X	X		X	X	X	X	X	X	X	X	X	
3.8 Modification	X	X	X		X	X	X	X	X	X	X	X	X	
4. SEPARATE SPACECRAFT														
4.1 Remove umbilical	X	X	X		X	X		X						
4.2 Disengage spacecraft	X	X		X	X	X		X						Release or arm release mechanism, DNA to Shuttle-provided retention devices
4.3 Transfer to spacecraft ground	X	X	X	X	X	X		X						
5. DOCKING OPERATIONS		*		*		*		*	*					*Expended S/C, unplanned only
5.1 Release boost locks	X		X		X									Apply to capture mechanism
5.2 Cock berthing mechanism	X	X	X	X										
5.3 Direct placement	X	X	X	X	X	X	X	X	X					Crew assist, viewing or placement
5.4 Engage docking latches	X	X	X	X	X	X		X						
5.5 Connect umbilical	X	X	X		X	X		X						
5.6 Connect to Shuttle ground	X	X	X		X	X		X						
6. PLANNED MAINTENANCE														
6.1 Install protective covers	X		X											Preparation for servicing
6.2 Install safety items	X		X		X		X							Preparation for servicing
6.3 Inspect spacecraft	X		X		X		X			X	X	X	X	
6.4 Access spacecraft and spares	X		X		X		X			X	X	X	X	
6.5 Remove and replace	X		X		X		X			X	X	X	X	Basic maintenance function
6.6 Load cryo coolants										X	X			
6.7 Clean sensors	X		X							X	X	X	X	
6.8 Repair mech items	X		X		X		X			X	X	X	X	
6.9 Service other fluid systems	X		X		X		X					X	X	
7. PREPARE FOR RETURN		*		*		*		*	*					*Expended S/C, unplanned only
7.1 Install/close contam. shields	X	X	X	X	X	X	X	X	X	X	X	X		
7.2 Engage entry latches	X	X	X	X	X	X		X		X	X	X	X	
7.3 Remove/stow/retract:														
.1 Antennas	X		X		X						X	X		
.2 Solar arrays	X	X	X		X									
.3 Instrument/booms/sunshade		X		X		X				X	X	X	X	
.4 Mechanisms	X									X	X	X	X	
7.4 Engage RMS/oper. stow device	X	X	X	X		X								
7.5 Retrieve film			X								X		X	
7.6 Stow/vent cryo supply		LH_e								LH_e	LN_2			
7.7 Stow/lock removed components	X	X	X		X	X			X	X	X	X	X	
7.8 Retrieve samples												X		
7.9 Inspect for entry	X	X	X	X	X	X	X	X	X	X	X	X	X	
7.10 Install shorting plugs	X		X		X	X	X	X	X					
7.11 Power deadface & switchover	X	X	X		X	X	X	X	X					
7.12 Drain/purge fluid systems	X	X	X		X	X	X	X	X	X	X	X	X	Vent to space or connect to Orbiter vent
7.13 Remove/stow power packs			X						X					

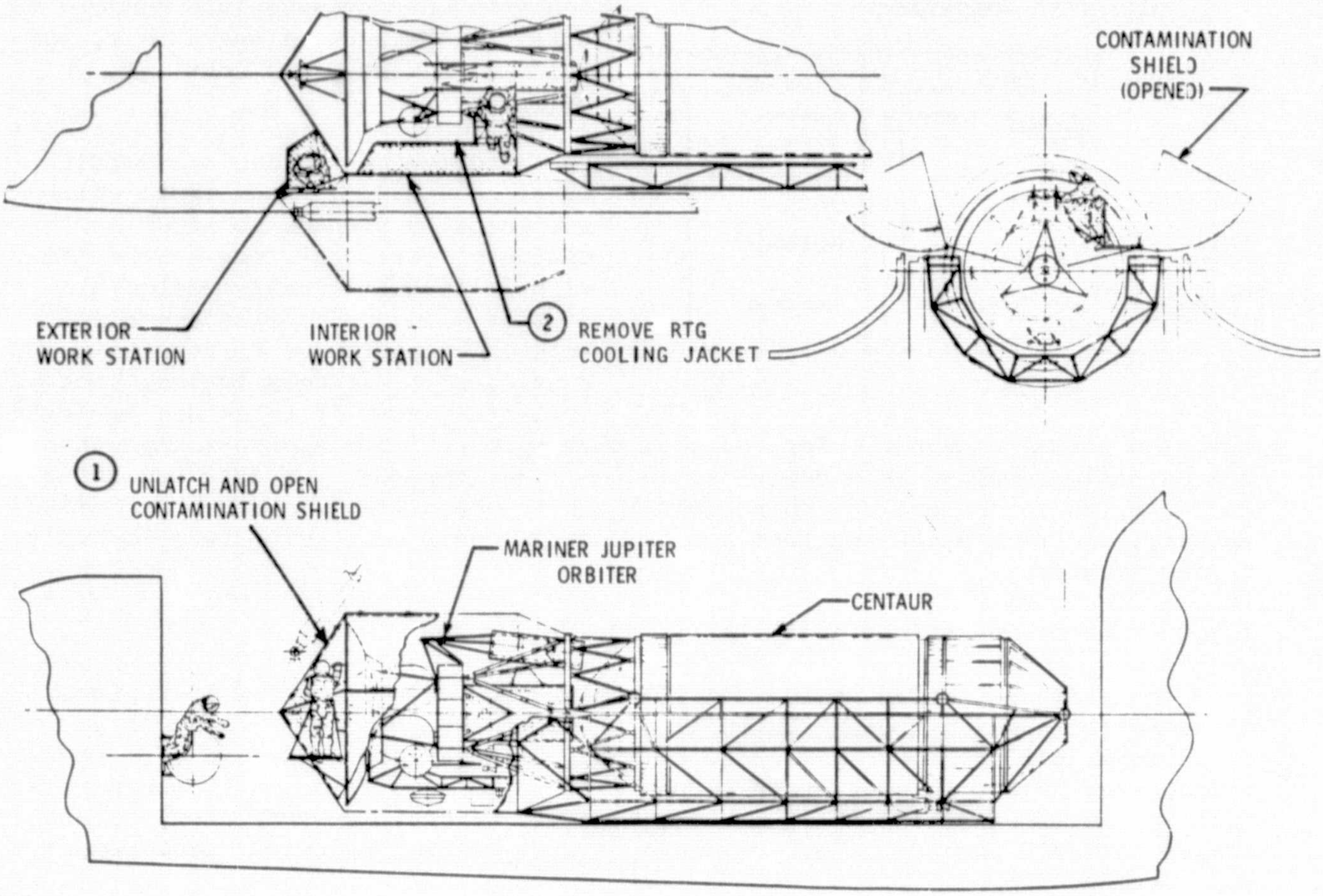

Figure 1-4. Typical EVA Applications for MJO Delivery

Table 1-9 summarizes estimated hardware item comparisons for automated and EVA approaches in accomplishing these functions. Removal of the shroud will require rotation of two cover segments to provide clearance for the MJO and attached upper stage to rotate out of the orbiter payload bay. A total of 32 items were estimated for the automated approach while for the EVA approach the requirement for only 6 manual latches is indicated. An alternate MJO concept for deployment of the contamination shield is to use pyrotechnics which are fired after separation of the MJO from the orbiter. Explosive separation devices not only present an added hazard potential but require additional reliability to ensure clean separation. Historically, failures in such systems have resulted in loss of mission.

The second function of RTG cooling jacket removal is estimated to require 20 hardware items for the automated approach while only 8 manual latches are estimated for the EVA mode of performing this operation. These reduced requirements indicate substantial cost savings in experiment hardware for these applications.

Table 1-9. MJO EVA Hardware Comparisons

AUTOMATED			EVA	
FUNCTION	HARDWARE	QTY	HARDWARE	QTY
SHROUD DOOR				
LATCH	MOTOR & SCREW ACTUATOR	4	MANUAL LATCH	6
EVENT SENSING	LIMIT SWITCH	12		
	DISPLAY	1		
SHROUD DOOR				
DEPLOYMENT	MOTOR & SCREW ACTUATOR	4	MANUAL ROTATION VIA HAND HOLD	AS REQ'D
EVENT SENSING	LIMIT SWITCH	8		
	DISPLAY	1		
COOLING JACKET				
LATCH	PYRO PIN-PULLER	4	MANUAL LATCHES	4
EVENT SENSING	LIMIT SWITCH	4		
	DISPLAY	1		
STOW COOLING JACKET				
RETENTION	MOTOR & SCREW ACTUATOR	4	MANUAL LATCHES	4
EVENT SENSING	LIMIT SWITCH	6		
	DISPLAY	1		

The results of the preliminary analyses were grouped into three categories: routine operations, payload maintenance, and contingency operations.

Routine operations in Shuttle missions are defined as those which are normally planned to occur on delivery, retrieval, and sortie missions. It specifically excludes planned maintenance missions and activities performed to correct a contingency. It does include routine activities even if these are performed out of a normal sequence. For example, docking activities are routine, but are not normally required on a delivery mission. If, however, a spacecraft anomaly was detected subsequent to separation, the crew would likely perform a routine docking, and then either perform a *contingency* repair or return the spacecraft to the ground.

1.2.3 Routine Operations Analysis

The analysis showed that a majority of the candidate routine operations involved the application of EVA in lieu of mechanized devices. Typically, these functions have been performed on orbit by a variety of designs, bi-stems, telescoping tubes, folding arrays, etc. They have been actuated by motor-reel, motor-screw combinations, spring-actuated devices, etc. However, they all have common economic considerations involving system design, hardware, procurement, and testing.

To assess the benefits of performing baseline payload routine operations by EVA, in lieu of electromechanical devices, a typical point design was selected. This design concept consists of electric motors, supporting structure, drive units, and the necessary control/display circuitry. The way in which EVA could replace such equipment was discussed previously. Typical costs for such equipment were developed based on historical data.

Based on the preliminary cost estimates of such devices and the number of such mechanisms on representative payloads, extrapolated cost estimates were made for the total payload model. As a result, the substitution of EVA manually operated devices was selected as a high-payoff area for carryover into the detailed analysis phase of the study.

The effects of other applications such as film loading, test and checkout, visual inspection, and payload safing were not readily quantifiable in terms of potential dollar savings in comparing EVA approaches to automated or teleoperator modes. However, sufficient potential for benefit was determined so that each area was analyzed further.

1.2.4 Maintenance Operations Analysis

The preliminary analyses of on-orbit maintenance considered both transportation costs and costs of servicing systems since such systems are considered to be part of the payload. Sortie payloads do not currently include any requirements for automated maintenance and consequently were not analyzed. However, the potential for EVA servicing of sortie payloads was recognized and included in the summary matrix.

For low earth orbit spacecraft (i.e., those in a Shuttle-compatible orbit), maintenance mission transportation costs are essentially equal in that Shuttle spares capability and time on orbit remain essentially the same. The demands of the automated and EVA approaches do not, on initial examination, vary substantially. Cost savings, therefore, are based upon estimates of the DDT&E and unit costs of the servicing aids and equipment multiplied by the number of those programs in the study payload model which call for planned on-orbit maintenance. The dollar value is the difference between automated or teleoperator costs and the cost of EVA support aids.

High earth orbit spacecraft may be serviced at Shuttle orbit or at the spacecraft operational orbit. Here, equipment and transportation costs vary considerably. In the best cases for EVA and automated approaches, program costs appeared nearly equal. However, further analysis was performed in the second phase of the study to determine sensitivity of the costs to differing traffic models.

1.2.5 Contingency Operations Analysis

By definition, contingency situations are those mission-interrupting or endangering situations for which no automated corrective techniques have been developed prior to flight. Therefore, use of EVA in contingency situations cannot be compared directly with automated approaches.

Deployment and stowing of payloads by means of EVA is less prone to failure than if accomplished by automated means (because of elimination of failure-prone electromechanical and electrical parts). If the probability of successful deployment is increased, the expected number of deployment failures is reduced. Assuming that a failure precludes experiment initiation, and that the experiment must be reflown, the cost benefit of using EVA can be as much as Shuttle launch costs, $10 million. If experiment retraction and stowage failures are avoided on the same basis, the costs saved would be increased because payload jettison would be avoided.

For free-flying payloads, cost benefits accrue from the application of EVA in improving deployment operations. Significant launch and payload cost benefits can be expected if EVA is used to reduce the probability of deployment and retrieval failures, either by eliminating potential failure modes through routine EVA usage or as a contingency option. Thus, an analysis was made of the major cost elements (i.e., transportation costs of automated spacecraft and sortie payloads, and sortie payload equipment) potentially impacted by the availability of a routine EVA capability. For example, whenever automated spacecraft fail, either attached to the Shuttle or in a Shuttle-compatible

orbit, there is a requirement for a relaunch if repair on orbit cannot be effected. EVA thus provides the potential for saving the relaunch cost, approximately $10 million, for each such case. Sortie payloads consist of various quantities of experiments. Costs of these were averaged on the basis of study data. Each experiment failure can require reflight or sortie equipment may require jettisoning without an EVA response capability.

Using the transportation and equipment cost factors and traffic model data, EVA savings estimates were made on the basis of probability of occurrence. The results of the estimates were shown to be of considerable significance. The detailed phase of the study analyzed types of contingencies and historical data to establish an appropriate rate for contingency occurrences and the resulting potential cost savings.

A summary of the EVA applications by mission categories and payload classes is shown in Table 1-10.

Table 1-10. Summary of EVA Applications

TYPE OF EVA APPLICATION	MAX QTY	AUTOMATED SPACECRAFT					SORTIE
		LEO		HEO			
		REUSE	EXPEND	REUSE	EXPEND	ESCAPE	
1. PRE-OPERATIONS	14	12	9	9	9	6	9
2. EXPERIMENT OPERATIONS	8						8
3. CONTINGENCY OPERATIONS	8	8	8	8	6	5	8
4. S/C SEPARATION	3	3	3	3	3		
5. DOCKING	6	6	5	5	4	1	
6. PLANNED MAINTENANCE	9	8		6			7
7. PREPARE FOR RETURN	13	11	7	8	8	7	9
TOTALS	61	48	32	39	30	19	41

II. DESIGN AND OPERATIONS ANALYSIS

Rather than initiating analyses on all 13 representative payloads at once, several preliminary activities were undertaken. Design requirements imposed on payloads by the orbiter were defined for the study. Orbiter support provisions to payloads and EVA were baselined and a set of EVA interface design criteria were adopted for the EVA configured payload designs.

An intensive review of mechanical elements common to most payloads was undertaken on the basis of precluding redundant analyses on each representative payload. Thus, the design of deployable solar arrays is essentially alike for any spacecraft employing deployable solar panels. Component parts, latch, release/deployment mechanism, and hinge element, are necessary and require similar design, reliability, testing, etc. Costs are, therefore, very similar for these elements, regardless of spacecraft. Variations in overall solar array assemblies as a function of such factors as square feet of array, pointing sophistication, structural loads, etc., do not affect the relative cost differences between manual and automated concepts. This section discusses comparative detail designs for solar arrays and similar mechanisms. These resultant design and cost data served as common building blocks for baseline and EVA-oriented payloads in design, task sequences, weight, and cost for the representative payloads.

Baseline orbiter timelines were defined to establish common ground for representative payload task analysis. Timeline building blocks were developed for detailed task segments. This had the dual purpose of ensuring standardization among representative payload sequences developed later, and of adding credibility to overall integrated timelines.

2.1 DESIGN REQUIREMENTS

Shuttle orbiter characteristics and payload interface requirements affect the design of all payloads, without or with EVA applications. Payloads designed for EVA interface must meet additional design criteria. While the study was not concerned with all aspects of payload design, a body of such requirements were necessary to ensure credibility of design solutions affecting study results. These data are not intended to reflect a current nor official set of design criteria. Neither is it intended to be comprehensive.

2.1.1 Shuttle Baseline Design and Payload Interface Requirements

This section only discusses general Shuttle requirements and mechanical, electrical, and fluid interfaces. Detailed requirements of the orbiter to payloads are specified in other Shuttle documentation.[1]

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[1] "Space Shuttle System Payload Accommodations", JSC-07700, Volume XIV.

Standard Payload Attachment Interface. Both the deployable and nondeployable payloads are required to provide attach fittings which mate with the orbiter. The orbiter attachment fittings, referred to as bridges, are removable and can be located to accommodate the payloads as required with only minimal restrictions (more specifically, 59 inches or 149.86 cm apart). Only those required for the mission are installed. For full diameter (15-ft) payloads, the bridge primary fittings contain alignment guides and payload trunnion latches electrically actuated by motors to ensure physical separation or retrieval. When the payload is latched in the trunnions, the guides are retracted. These alignment guides position the payload trunnion fittings with an accuracy compatible to the tolerances required for on-orbit retrieval of payloads using the RMS. Figure 2-1 illustrates typical payload retention points.

Electrical Power Interfaces. The orbiter provides power transfer to interfaces at X=693 (mid-bay) and X=1307 (aft bay). The mid-bay interface will transfer 12 kw (max. rated output from fuel cell 3) or 8 kw from main bus B. A payload chargeable kit may be used to route the 8 kw to a separate interface at the same station. Two 2-kw feeders provide power to the aft bay interface. Power feeders from separate orbiter sources shall not be tied together except for two 20-amp emergency feeders which have a separate interface at X=693, and are mechanized to be tied together (total 20 amps) without additional payload circuitry.

Two or more power feeders to the payload may be used simultaneously, but in no case may two orbiter power sources be tied directly together within the payload. Therefore, any payload equipment requiring electrical power from two separate orbiter sources will be required to assure isolation of these sources such that no single failure or condition will cause an out-of-limit condition on the orbiter subsystem equipment.

Payload Service Panels. Many of the fluid service provisions in the payload bay are to provide an interface to cryo-propulsive payloads, storable propulsive payloads, and OMS delta-V kits. These same fluid provisions can be used by all other payloads assuming availability, compatibility of fluids with the panels and lines of the orbiter, and safety factors based on the type of fluids involved.

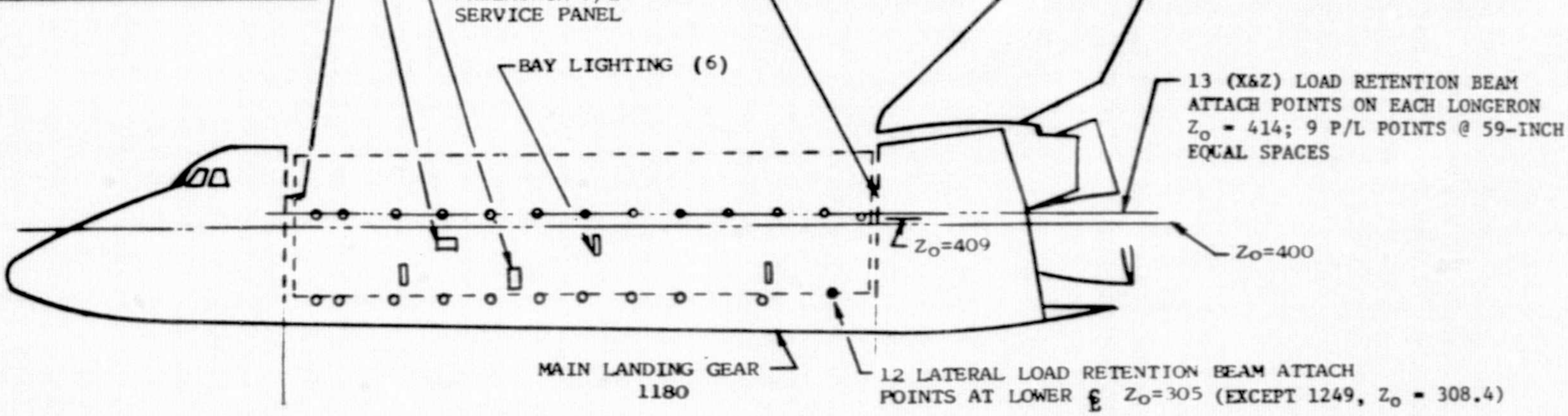
Payload services and utilities are found on both the forward and aft bulkhead. The fluid service panels are mounted on the aft bulkhead. The orbiter will accommodate additional fluid lines from the payload to the interface connectors; however, space is at a premium. The orbiter also provides for the dumping of upper stage fluids during abort modes; but the payload must provide the dump line from the payload to the aft bulkhead.

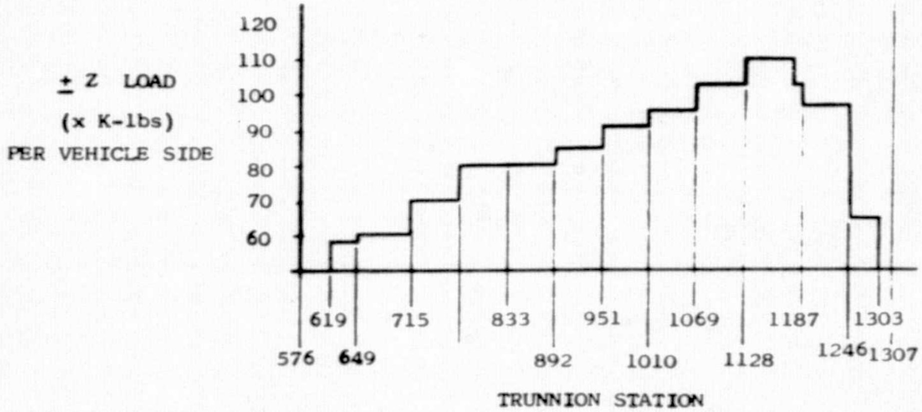
A payload heat exchanger is proposed outside the payload envelope but within the bay area consisting of four fluid line quick-disconnects and two independent and redundant coolant loops.

Design load requirements imposed upon the orbiter payloads are listed in the referenced source data to indicate the payload design-to-load factors. Two cases are given: (1) for 65,000 pounds (29,484 kg) up and 32,000 pounds (14,615 kg) down, and (2) 65,000 pounds (29,484 kg) down. It is noted that only the maximum design-to conditions are stated and only for critical mission phases. These loads were considered in the EVA-oriented design concepts as they affected weight and sizing.

CARGO LIMIT DESIGN ACCELERATIONS
65K UP 32K DOWN

LINEAR 'G'			
CONDITION	X	Y	Z
LIFT-OFF	-0.1 -2.9	+1.0 -1.0	+1.5 -1.5
BOOST MAX ORB ALONE	-2.7 -3.3	+0.2 -0.2	-0.75 -0.75
LANDING	+1.0 -0.8	+0.5 -0.5	+2.8 -2.2
CRASH	+9.0 -1.5	+1.5 -1.5	+4.5 -2.0





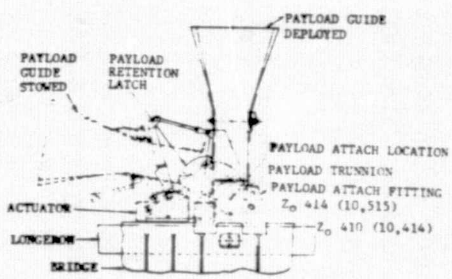


Figure 2-1. Shuttle Design Requirements and Support Provisions

2.1.2 EVA Design Requirements

Design analyses were initiated by assembling design requirements and constraints which would be applicable to systems and subsystems with planned EVA activities. The topics covered in the selected design requirements include the following:

Type of Requirements	No. of Requirements
1. EVA reach capabilities	3
2. Visibility (lighting) during EVA	6
3. Handhold, tether, translation, rail, and foot or body restraints for EVA mobility or force application	14
4. EVA translation paths (volumetric clearance)	3
5. Pressure suit mobility guidelines	2
6. EVA mass handling considerations	7
7. EVA tools and equipment	21
8. Work station layout and provisions	7

MSFC Standard 512[1] was a primary reference source for the selected data. Selections were made or modified based on reported Skylab experiences and recent or current EVA studies.

Figure 2-2 illustrates a typical EVA application requiring lateral force application. In this example specific detail design criteria and EVA limitations are called out. In the course of the study, such detail was not provided on each drawing; however, the same consistent level of attention was applied in preparing the design layout and all EVA supporting provisions were referenced for costing purposes. It should be noted in this example that options exist which potentially involve new requirements on EVA system aids. The rigid restraint shown is typical of previous concepts of a telescoping rigidized bar permitting force application. An alternate approach would provide a structural pad on the workstand and allow the astronaut to use his knee for reaction. This would require that the design of the PGA knee accept such stress but would have the advantages of increased flexibility of body position, elimination of the time to set up the telescoping bar, and improved translation mobility without bars attached to each side of the crewman. Another potential EVA design requirement is shown in the backpack-mounted lighting concept. In this region of the representative payload there are no suitable positions for placement of fixed lights unless a "light-pole" fixture were to be installed. However, battery-powered mobile lighting over the shoulder could be provided as shown.

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(1) "Standard Man/System Design Criteria for Manned Orbiting Payloads", MSFC STD-512, 12 August 1974.

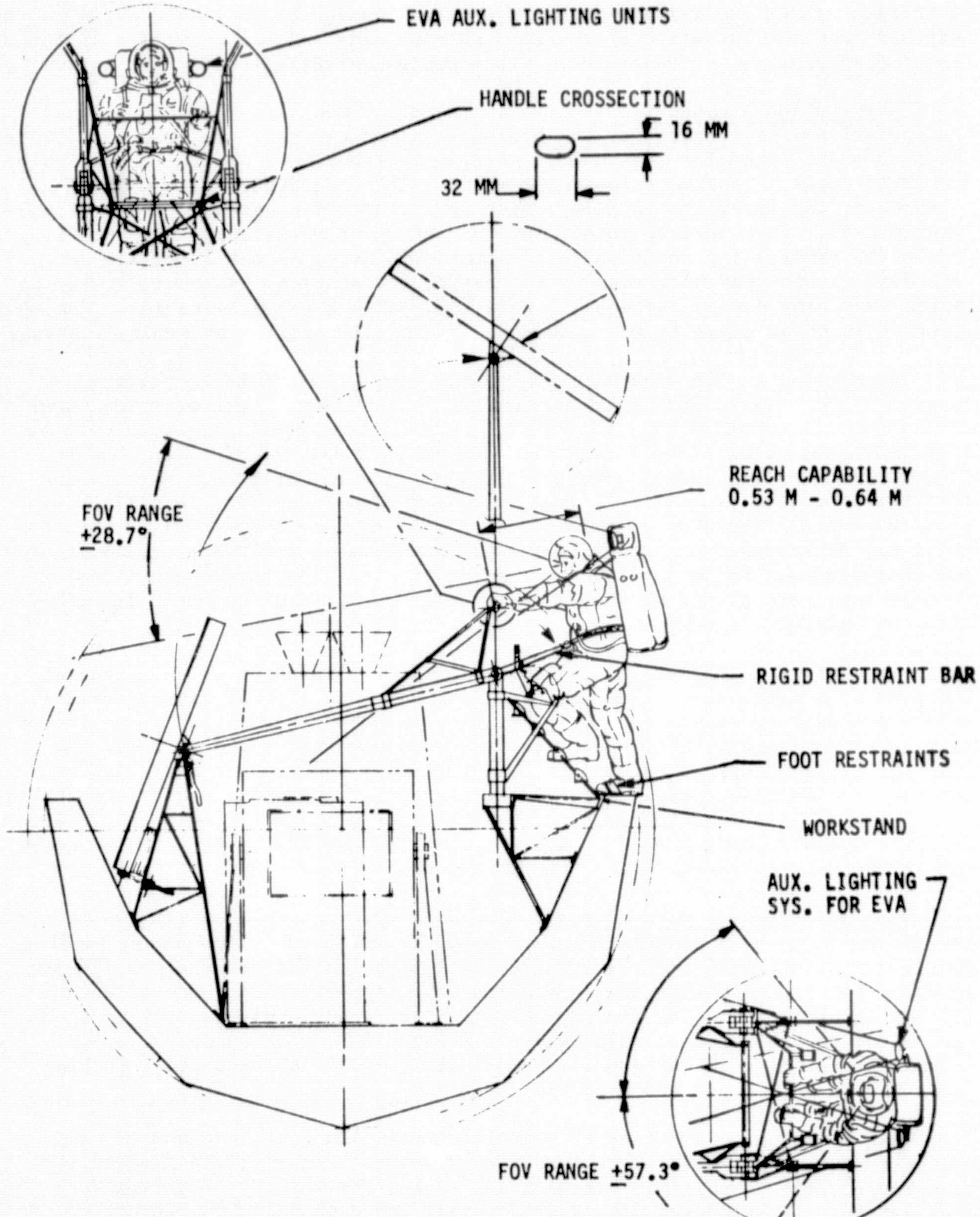


Figure 2-2. EVA Design Constraints in Lateral Force Task (Search and Rescue Imaging Radar Antenna Deployment)

In Figure 2-3, various similar design criteria are seen to be applied for a vertical force application task. Additional considerations were given to the exposed edge configuration of the horn antenna ring and the provision of latches for the antenna stowed restraint. Other design criteria include the following.

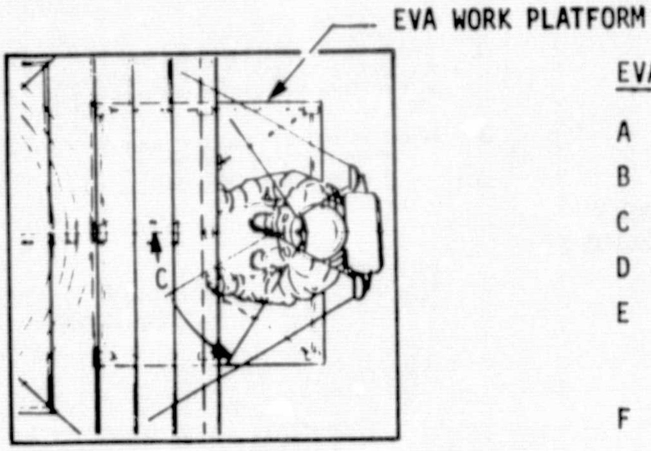
Workstation Accessibility. EVA workstations must provide good accessibility to operational interfaces for the pressure suited crewman. It is desirable to have adequate space for 2-hand work envelopes with allowances for operation of handheld tools. In some cases, equipment will be required to be unstowed, assembled, and later stowed (i.e., microwave radiometer antenna horn deployment, Figure 2-4). It should be noted that the astronaut workstation need not always be in the typical 1-g position to perform some tasks; he may literally be standing on his head with respect to Shuttle orientation. However, it may be noted that many design concepts in this study show a 1-g orientation. The objective in these cases is to accommodate ground preparation or evaluation activities.

Illumination. The astronaut may remain EVA up to six hours passing through light/dark illumination periods up to four times. Consequently, some artificial illumination will be required. Specifically, illumination will be required along translation routes during dark periods. In addition, due to illumination angles, obstructions, and reflections the astronaut may require that his immediate frontal work area be illuminated. The Shuttle will only provide general cargo bay illumination. Either permanent fixtures or portable units may be provided by the payload, which could also provide adequate light for photography. While payload surfaces may reflect light throughout the Shuttle bay, care should be taken not to generate glare which would interfere with the astronaut's performance.

Translation Route Design. All EVA translation routes must be adequately equipped with translation aids, such as handrails and lights. The translation aids are also discussed under Restraint Devices. The translation route itself must be of an adequate envelope free of protrusions that could entangle the crewman or his backpack. Equipment transported by the crewman must also be considered. Another factor to consider is adjacent equipment protection during translation. Equipment located adjacent to translation paths must be protected if contact would contaminate, damage, or misalign any item. Protective covers may be temporarily installed by the EVA crewman.

Hardware Strength Capabilities. The maximum strength capabilities of the crewman are affected by the particular pressure suit used. Fasteners, handles, doors, and other equipment requiring operations by an EVA crewman should have an actuation force of less than 156 N (35 lb). An actuation force of 45 N (10 lb) is preferred. The minimum actuation force obviously depends upon the particular hardware, but should be great enough to provide feedback to the crewman to indicate latching/unlatching. Equipment which requires a pushing force should not exceed 260 N (60 lb).

Mass Handling. Selection of manual, manual-aided, and mechanical cargo transfer devices depends on the frequency of cargo transfer, the mass to be transferred, the translation distance and route, possibility of damage and crew safety. Experimental data indicate that approximately 3900 kg may be handled unaided and is not likely to be damaged.



EVA CONSTRAINTS

A REACH CAPABILITY 0.53 M - 0.64 M

B FOV (VERTICAL PLANE) ±28.7°

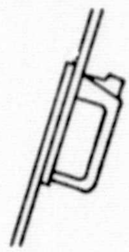
C FOV (HORIZ PLANE) ±57.3°

D RADIUS OR FOLD ALL EXPOSED EDGES

E PAYLOAD SURFACE MATERIAL SHALL BE COMPATIBLE WITHIN TOUCH TEMPERATURE LIMITS FOR SUIT GLOVES -70°C to +93°C

F DEPLOYMENT HANDLE WITH TRIGGER LATCH

- PUSH BUTTON OPERATION
- GLOVED HAND DIMENSIONS



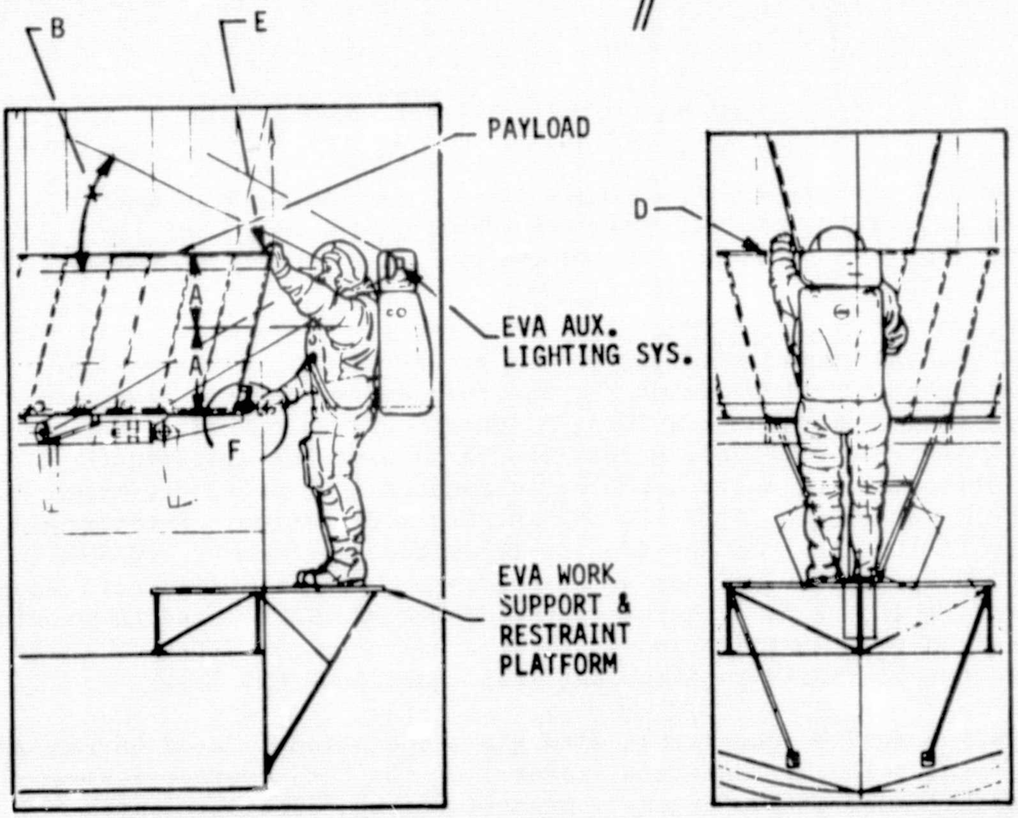


Figure 2-3. EVA Design Constraints for Vertical Force Application (Structure Erection)

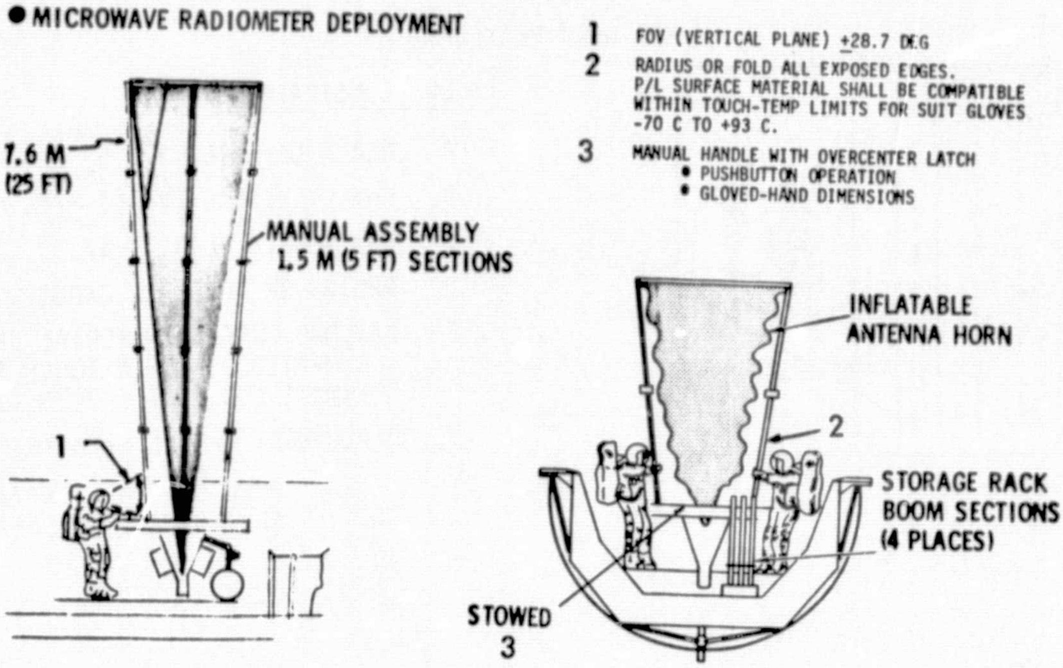


Figure 2-4. EVA Design Application for Extension Device

The nominal size for equipment for a single crewman, which ensures his visibility is 70 cm (28 in.) in any two directions with a length of 1 m (3.3 ft). Items larger should use two crewmen and if possible, a manual-aid device.

Manual Removal/Installation Interface. For replaceable modules, all forward edges of a package should be visable to the restrained crewman during alignment and attachment. This includes connectors and mechanical fasteners. If adequate visibility cannot be provided, alignment arrows or marks should be used. Where alignment is critical, guides should be used for assistance. Removal/installation forces, where hardware is mounted into a capture-type receptacle, should not exceed 156 N (35 lb) in either direction. Rotational forces should be limited to 2.25 N-m (20 in.-lb) with a maximum of 4.0 N-m (35 in.-lb) depending on size and design of handles. Where visual verification is not sufficient, a detent or over-the-center device should be used to provide tactile verification that installation or locking has occurred. Detent forces should be sufficient to verify position but less than 156 N (35 lb).

EVA fasteners should be compatible with glove operation. Based on Skylab II and III crew evaluation of fasteners, several of the hand-operated-types are listed in their order of preference: magnetic latch, container latch (spring clamp operation), panel/door handle and trigger latch, pip pin fastener (push button), and container latch (T-bar and lever).*

*See Figures 2-11 through 2-15 for examples.

For threaded-type fasteners the preferred type is the internal hex head screw. All removeable equipment should be mounted with the same type and size of fastener using a common tool. Adequate clearance should be made to accommodate a gloved hand holding a tool.

Manual Dexterity. The degree of dexterity possessed by a suited crewman is a function of the type of suit used. There is a requirement for fine manipulative tasks to be performed. Tactile feedback is somewhat diminished by the EVA glove and internal pressure, however, is generally acceptable with current or advanced suit design.

Restraint Devices. EVA tasks can be simplified if adequate crew restraints are provided. These restraints should generally consist of foot restraints, handrails, waist and chest tethers. All foot restraints should provide positive restraint capable of withstanding 445 N (100 lb) and permit easy ingress/egress without danger of entrapment. Where foot restraints are used, a handhold should be positioned at waist to shoulder level. These handholds should be capable of supporting 556 N (125 lb) in any direction and colored to stand out against any background. Additional load capability should be considered where crew equipment handling is required. Double handrails may be used to assist translation and to act as a protective guard about delicate or sharp instruments.

Reach Envelope. Assuming that a foot restraint is used in combination with a chest-level handrail and that the crewman is free to move from left to right while in the foot restraint, workstation hardware requiring operation by an EVA crewman should conform to the reach limitations illustrated in Figure 2-5.

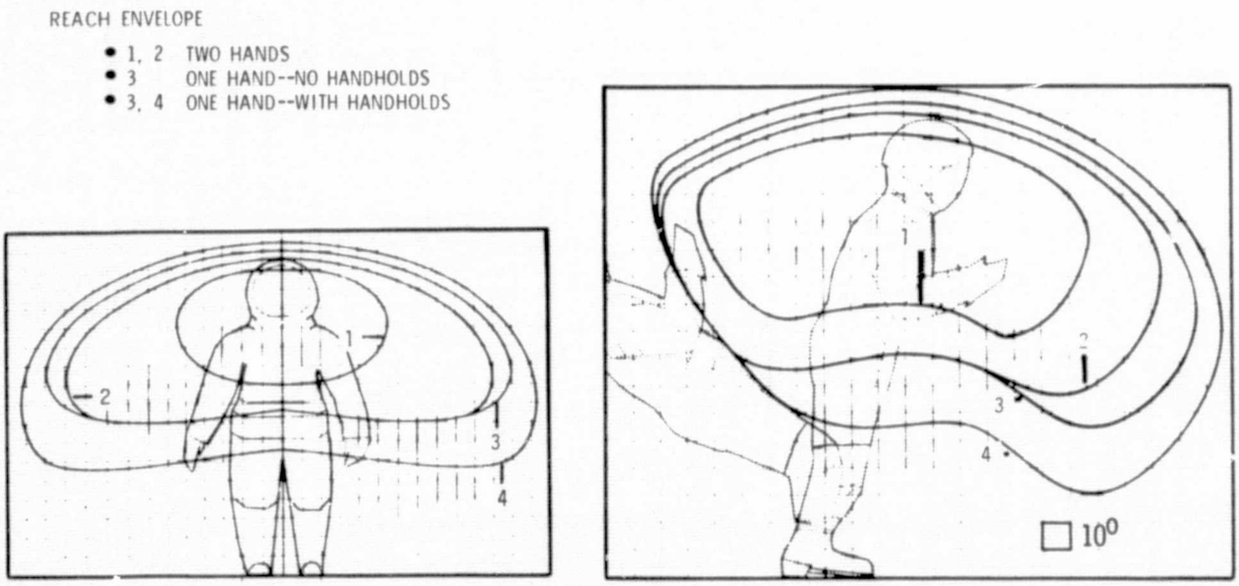


Figure 2-5. Suited Astronaut Reach Envelope

2.1.3 Shuttle Provisions

In order for a proper analysis to be made of the various needs and requirements for payload servicing, it was necessary to baseline the capability of the Shuttle system. Particular emphasis was placed on provisions to support EVA and on the Shuttle Remote Manipulator System (RMS). The RMS was reviewed both in terms of a system capability and to provide a base for comparing it to EVA.

EVA provisions in the Shuttle include all basic equipment and consumables to conduct EVA at no charge to the payload. Although various aspects of the provisions are currently under study in the Shuttle program, Figure 2-6 illustrates pertinent EVA Shuttle provisions. The Shuttle airlock is expected to have a pre-mission option of being installed inside or outside (in the cargo bay) the cabin envelope on the cabin bulkhead. Suits, life support backpacks, prebreathing oxygen, and airlock atmosphere are planned to support up to three, 2-man, 6-hour EVA's. One of which is reserved for Shuttle contingency.

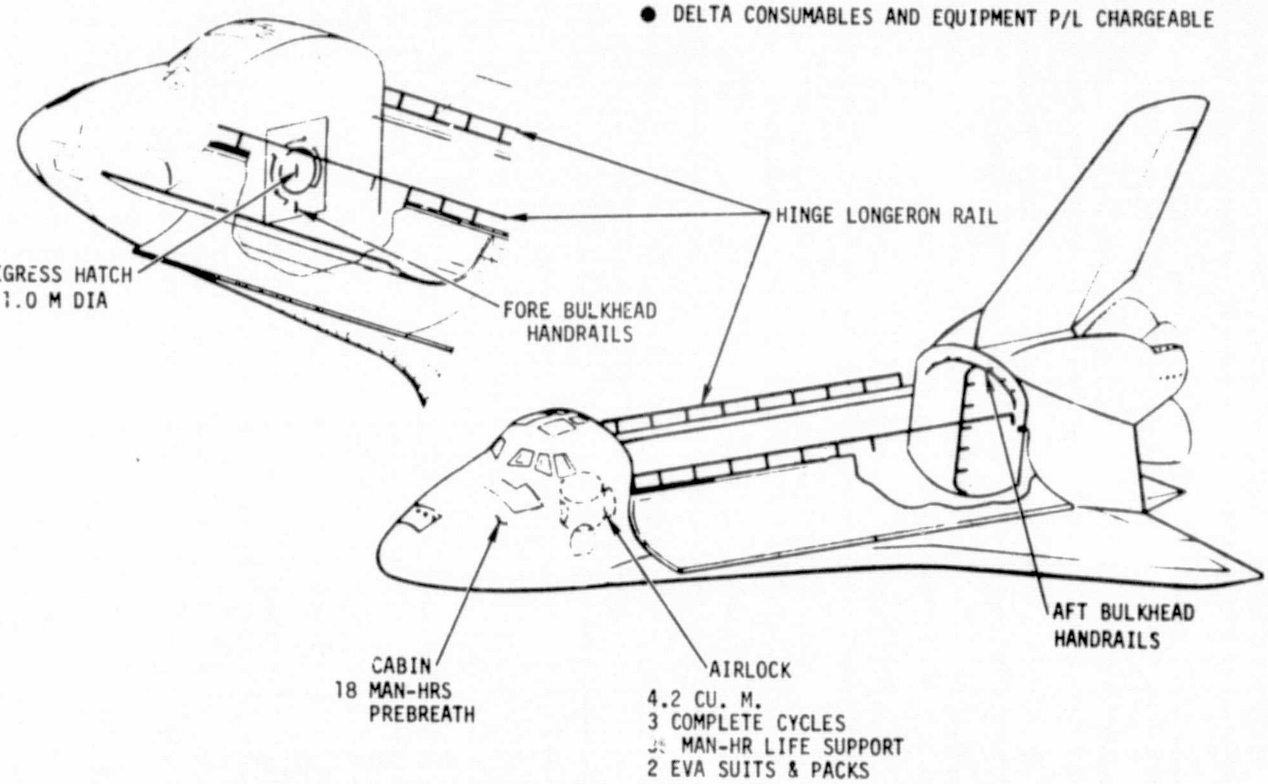


Figure 2-6. Shuttle EVA Provisions

Remote Manipulator System. The RMS is designed for use in zero-g handling of payloads. The mechanism will assist in the deployment and retrieval of payloads and can be used to inspect payloads, both in the orbiter bay and in space prior to attachment. Several end effector devices are currently undergoing investigation to propose a standard inventory which may be provided by the orbiter.

However, the current RMS concept has limitations on its capabilities. For example, no force feedback has been defined to date. Also, due to overall length, the end effector tip force is limited to 45 N (10 lb). To date, no rotation requirements have been specified, although some payloads have indicated a use for rotational capability for the RMS. CCTV is provided by placing a TV camera at the operational end of the RMS but with the limitation of monocular viewing (lack of depth perception).

In considering operational uses of the RMS, especially as an alternative to EVA, two main areas were analyzed. These were direct viewing by the crew and the remote manipulator system access.

Direct Viewing. The orbiter has three payload viewing windows, one having an 80-degree conical field of view through the top of the cabin and two windows with a 62-degree conical field of view through the cabin bulkhead looking aft. Figure 2-7 depicts a top and side view showing inaccessible viewing areas.

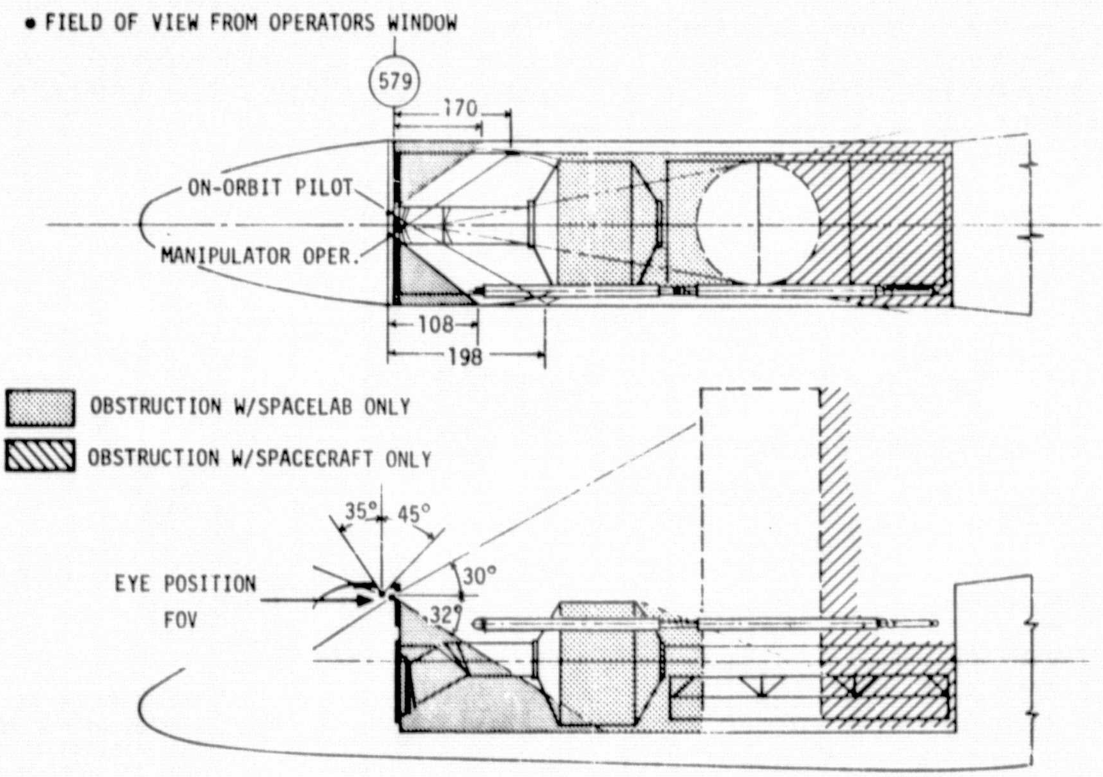


Figure 2-7. Spacelab Constraints on Cargo Bay Viewing and RMS Accessibility

The figure shows two triangular areas which are always obscured due to the bay window locations regardless of whether a payload is mounted within the bay. The figure also indicates the further loss of direct viewing in the bay with a Spacelab installed. The entire aft portion from the Spacelab on becomes obscured to direct astronaut viewing. For those payloads requiring a Spacelab or those having a pallet with large equipment mounted near the observation windows, CCTV is mandatory for any viewing requirements. Finally, the figure shows a large vertical cylinder proximately positioned in the orbiter bay. The area forward of this type payload, including the payload, is visible; but note that the entire payload aft area, including the vertical stabilizer, is obscured by the payload itself. It should also be noted that with large vertical payload elements such as a telescope or for a payload having long extended projections (AMPS), maneuvering of the manipulator around such obstacles may also be difficult or impossible.

Automated spacecraft will appear in various configurations while in the bay. This includes parallel to the longitudinal axis of the orbiter as during the launch phase. The forward end of installed spacecraft, up to the RMS shoulder void at least, and an arc over the upper surface of the spacecraft are the only spaces accessible to the RMS. When payloads are erected within the bay or have protuberances beyond the orbiter mold line, they interfere further with the total effectivity of the RMS. The worst case appears when the spacecraft has a uniform maximum diameter equal to that of the bay width and is positioned at the mid-point as illustrated in Figure 2-8.

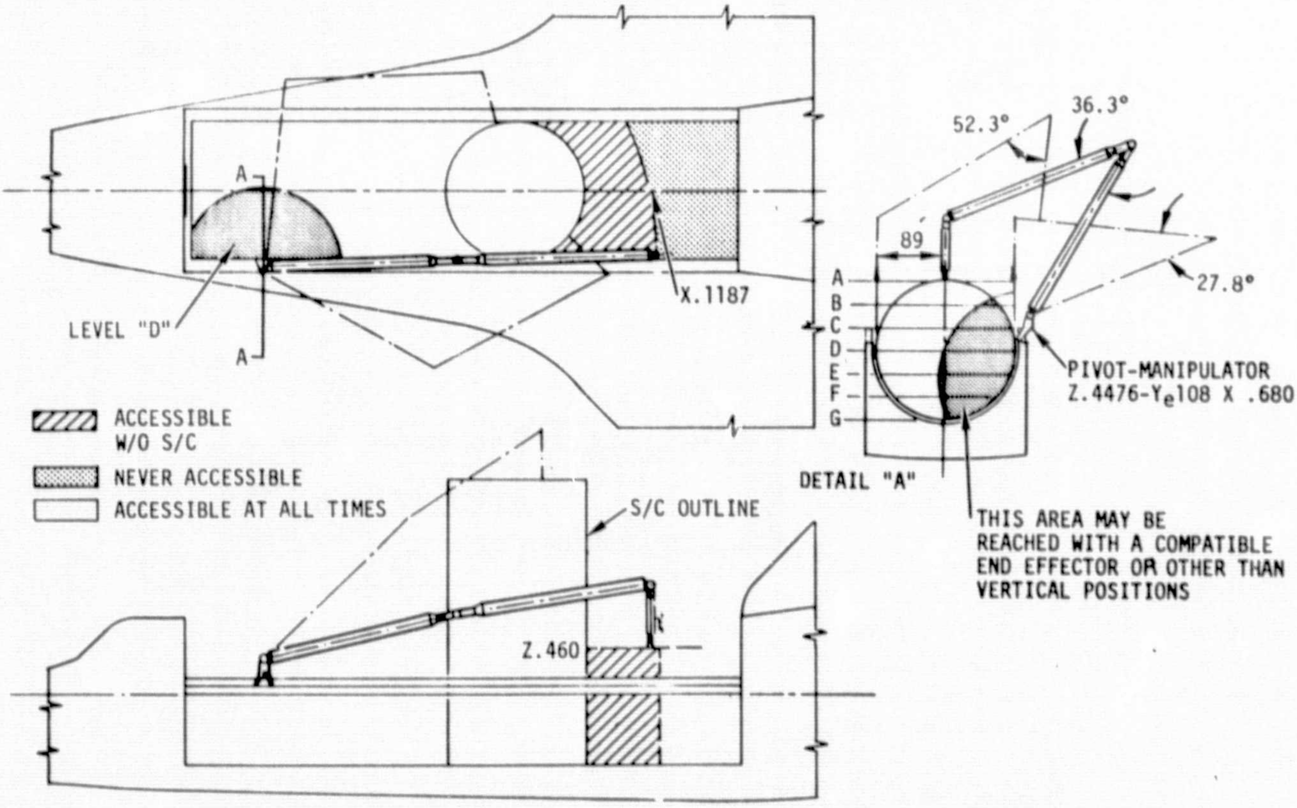


Figure 2-8. Spacecraft Constraints on Cargo Bay RMS Accessibility

The envelope shown for an erected spacecraft represents a position found to be valuable in delivery and servicing operations. By partially or fully raising the spacecraft out of the bay, deployable antennas, solar panels, etc., can be placed in their operational position. This not only improves the scope of pre-separation checkout, but ensures proper deployment before committing to umbilical separation. However, use of the deployed spacecraft position is dependent on either the RMS for support, or an additional special purpose mechanism. Thus, when the RMS is used it is not available for other uses (unless the payload chargeable second arm is carried to orbit).

It is noted that the RMS requirements are currently being developed in detail by NASA.

While the RMS is the selected mode for payload deployment and retrieval, its effectiveness and flexibility in performing other tasks are impaired by physical constraints and even more by installed payload elements as discussed above. The RMS as presently envisioned, Figure 2-8, consists of five sections:

1. Shoulder actuator - actuator mechanism connecting RMS to orbiter
2. Upper arm - 6.7 m (22 ft) length
3. Lower arm - 6.7 m (22 ft) length
4. Wrist actuator - 1.2 m (4 ft) length
5. End effector - 0.6 m (2 ft) length

With the RMS sections attached as above, the total effective length is 15.2 m (50 feet). In this configuration and even with an empty orbiter bay, two areas cannot be reached physically by the RMS. These areas are directly in the vicinity of the RMS shoulder actuator and the aft end of the bay including the aft bulkhead.

In considering various EVA/RMS task comparisons, RMS was evaluated with respect to access and flexibility for typical spacecraft delivery preparation and planned maintenance. Figure 2-9 illustrates the complexities of RMS interface for modular exchange including the special end effectors and self-alignment connectors. The figure also illustrates some of the access problems involved in the use of the RMS for detailed task performance. For example, the RMS access could be impaired if the solar panel were deployed rather than retracted as shown, thus requiring additional design complexity for RMS or remotely operated retraction. Furthermore, the RMS cannot reach side or underneath components, unless special erection and rotation provisions are provided (e.g., EOS-type of erection platform or a second payload-chargeable to RMS). This would prevent the RMS from performing any EVA task such as umbilical make/break and would make payload retention latch release difficult. Further problems in comparison to EVA are that if the RMS released the payload retention latches, it must quickly secure the payload to prevent free drift. Another problem in using the RMS is the lack of positive indication feedback; i.e., "latch released", unless talk-back circuits of the remote system are retained.

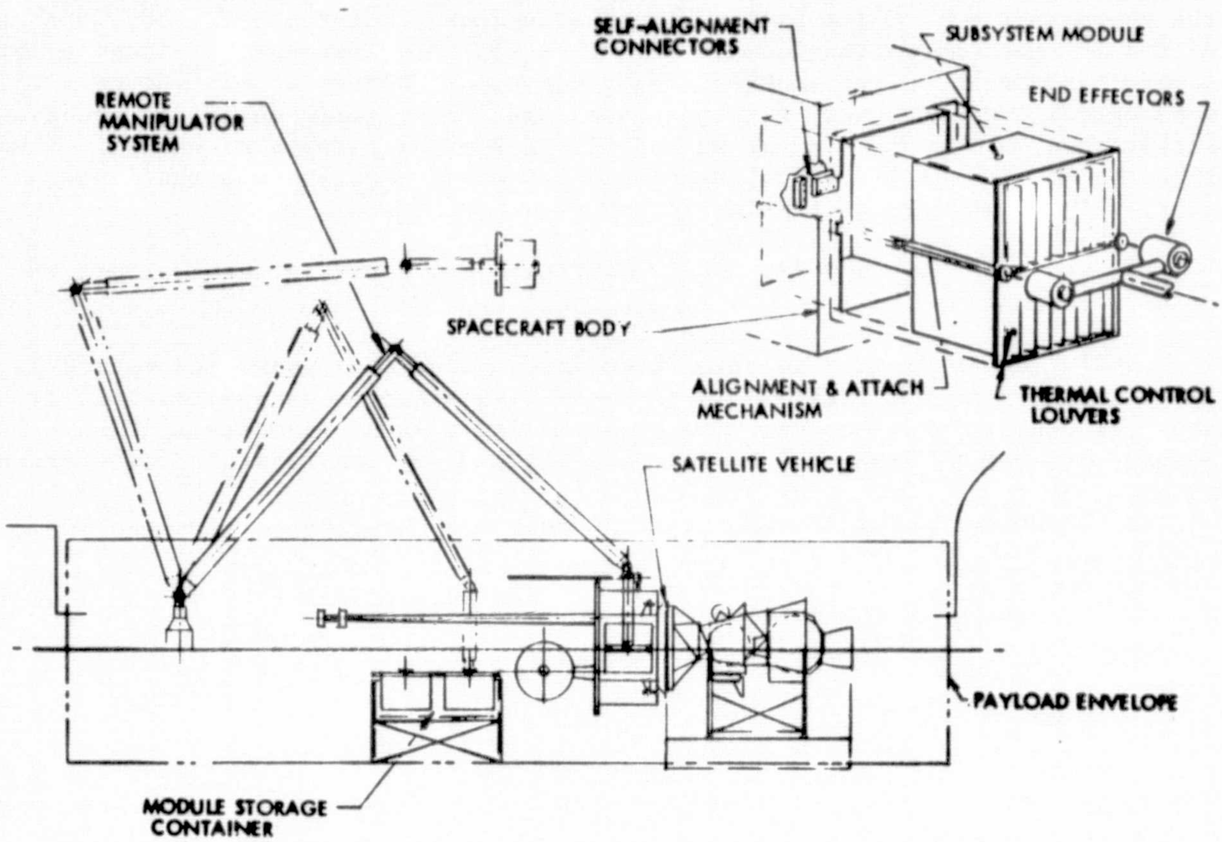


Figure 2-9. RMS Task Performance Concept

One of the beneficial uses identified in the study for the RMS was to assist EVA tasks by retaining the payload in a suitable work position. An example, shown in Figure 2-10 of the Gravity and Relativity Satellite, is based on maintaining two retention points on the pallet-mounted retention frame, while the RMS provides a third stability point. By raising the spacecraft to this position, the solar panels can be fully extended in all four axes thus improving the overall spacecraft checkout before umbilical separation. It is desirable (if not necessary) to retain an umbilical connection during the completion of the checkout activity to verify operational readiness. Extending the umbilical to the raised position can readily be performed manually, but would require additional complexity in the automated umbilical concept. The EVA work platform shown could be oriented in various attitudes, but was placed in this position on the basis of being useful during ground procedures as well as on orbit.

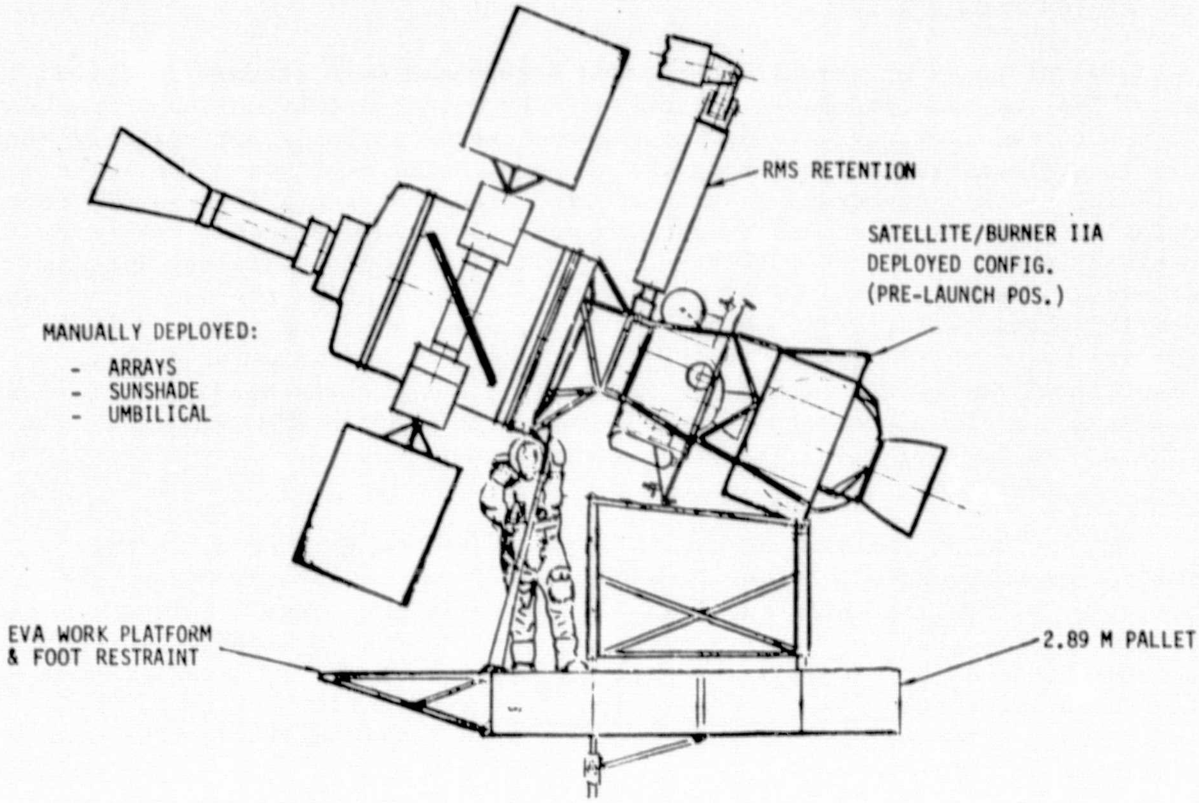


Figure 2-10. RMS Assist to EVA Activities

2.2 DESIGN ELEMENTS ANALYSIS

Several types of normally automated mechanisms were studied in detail to derive EVA and teleoperator alternatives. By detailed examination of mechanisms which occurred frequently among the representative payloads, it was only necessary to evaluate variations among the representative payloads. The basic "building blocks" discussed in this section also add credibility to the representative payload design and operations analysis. Data sources, whenever possible, were for actual flight hardware which is appropriate for Shuttle payloads. Manual designs were then established to perform the same function. Detailed characteristics of weight, cost, complexity and reliability were examined based on EVA design since these in general had no prior design. These manual design cost estimates were established on the basis of material, manufacturing technique, and relative complexity--or, in some cases, on the basis of the cost of specific hardware components deleted.

Evaluation of deployed mechanisms shows that the Shuttle cargo bay envelope as with expendable boost shrouds tends to required stowed solar panels and various retention devices during the launch phase. However, where one-way (or one shot) mechanisms are acceptable in the expendable booster case, payloads planned for retrieval or payloads which could be returned to earth after on-orbit checkout failures require two-way operation. Since overall Shuttle cost effectiveness is only achieved with retrievability, this case was postulated in this study.

Specific items analyzed in detail were retention latches, deployment mechanisms, and umbilical make/break mechanisms. Retention latches are required for the payload (spacecraft) itself as well as for every "movable" element which forms a part of an operational spacecraft or sortie payload. This requirement for "tie-down" of movable elements applies to the Shuttle boost phase (where ground installation crews ensure latching) followed by on-orbit release. Subsequently, for retrieval of spacecraft or Spacelab payloads, latching is required for entry and landing.

All deployable devices must be extended on orbit to perform their function and must be retracted within the Shuttle mold line. This may apply to solar panels, extendable booms, antennas, and telescopes.

Another significant class of mechanized elements exists with umbilicals providing signal, power, or fluid interface from the Shuttle to the payload. Requirements exist for Shuttle power to be provided to many spacecraft. In turn, the Shuttle requires safety monitoring of payload critical circuits plus potentially some control or checkout provisions. Many spacecraft require fluid venting or dumping via Shuttle plumbing. Two-way (break-remake) operations again are required for any possible retrieval capability. Candidate designs were studied for automated, EVA or RMS actuated modes.

2.2.1 Deployment/Boost Latches

Five different deployment latches were analyzed in their automated version, and EVA design alternatives were developed for each. The five types were: (1) solar panel, (2) antenna, (3) sensor cover, (4) scanning platform, and (5) payload retention. Weight savings by EVA were found to be minimal, while unit cost savings vary from negligible on the simplest mechanism to several thousand dollars on the most complex. The most significant cost savings are related to the program cost of qualification. Each different latch on each project would be run through a separate qualification program, whereas, all EVA operations on one mission or series of missions would be covered by generalized training. Redundancy of design functions and super-high reliability of one-shot devices would not be required with EVA unlatching. Use of EVA eliminates control wiring, talkback signals, data link channels, control console, and display functions.

A remote-controlled latch mechanism generally consists of four separate functional parts:

1. A latch--hook, pin, bar, link, etc.

2. A clamping feature--toggle, spring, screw, piston, etc. to provide a required locking force

3. An unlatching device--spring, etc., to effect a positive removal of the clamping feature and/or to remove the latch from the deployment envelope

4. A release actuator--a trigger, solenoid, pin puller, pyro, etc. to initiate the unlatching device

Additional equipment complexities to provide redundancy or special features unique to the release and deployment requirements of that article may also be required.

An EVA latch mechanism would generally consist of a latch and a clamping feature, but the unlatching device and release actuator would be combined into a single manual-actuation feature. Redundancy and some special features would not be required on an EVA latch mechanism.

The significance of the EVA approach would be related to the complexity of unlatching and release actuator components and equipment complexities no longer required.

The specific latch mechanisms evaluated are:

1. Solar panel latch (Rockwell Global Positioning Satellite)
   (In-house on-going hardware contract, FO-4701-74-C-0527)

2. High gain antenna latch (JPL, 1971 Mariner Mars)
   (JPL "Space Program Summary", Report 37-60, Mariner Mars 1971)

3. Science cover latch (JPL design)
(JPL Technical Report 32-832, "Mariner IV Science Platform Structure and Actuator Design, Development and Flight Performance", November 15, 1965)

4. Scan platform latch (JPL 1969 Mariner Mars)
(JPL Special Programs Report 37-55, Vol. I, Flight Projects for the Period November 1 to December 31, 1968, dated January 31, 1969)

5. Payload Retention Latch (Rockwell EOS/FSS concept)
(In-house study contract, NAS5-23203)

Size and weight are not significant considerations in an EVA replacement since the total envelope on three of the four mechanisms are within 1000 cc and 0.9 kg weight per latch.

The automated solar panel latch consists of the following elements:

Latch - roller latch

Clamp - link

Unlatch - spring

Release - pin puller, fuze wire type

Complexities - boost spring

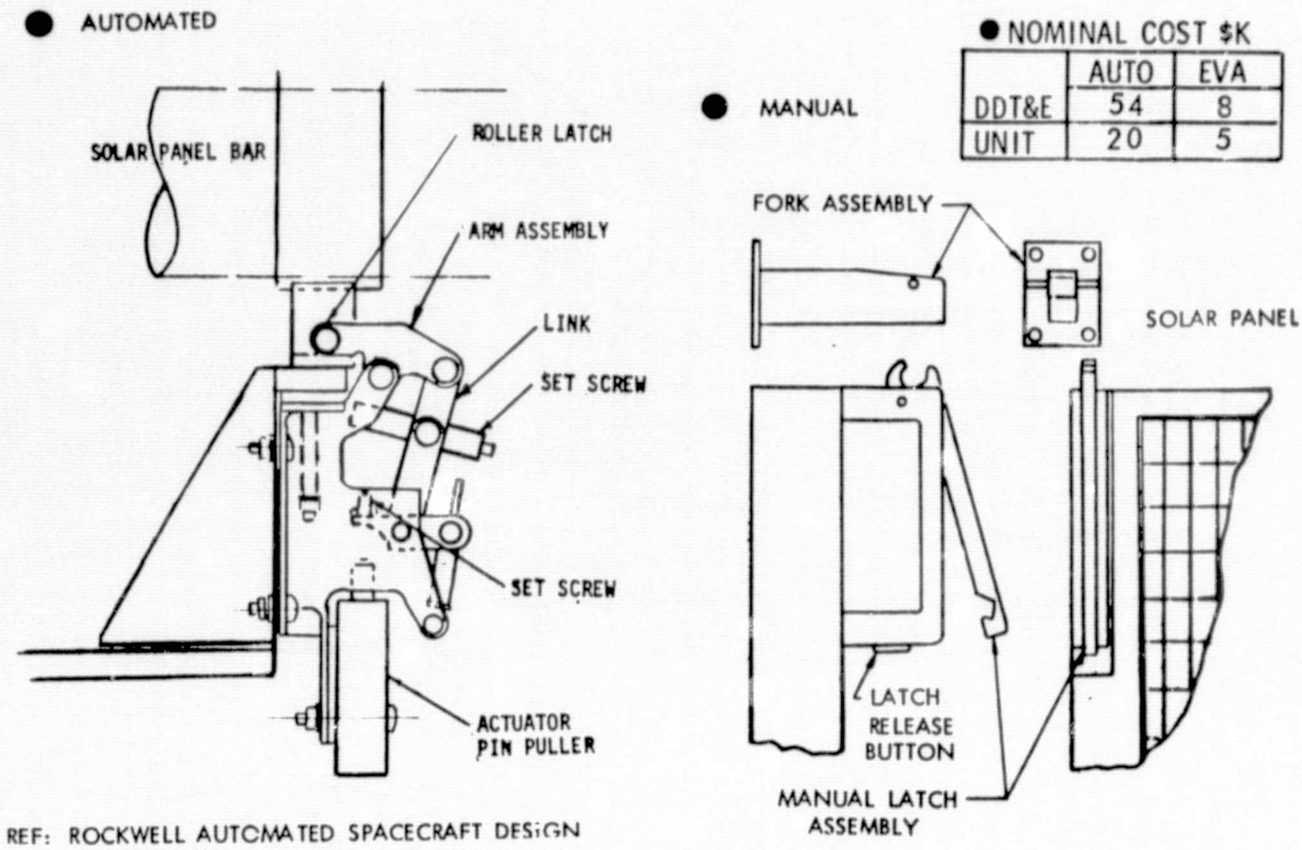
The extreme reliability required of the one-shot pin puller and its flight qualification testing represent a program cost much higher than the unit cost. Also, the one-shot pin puller is not compatible with after-assembly testing nor retrieval operations.

Figure 2-11 illustrates both the automated design approach and an EVA-oriented design simplification for the solar panel latch. The purpose of the latch is to restrain the solar panel assemblies during boost and then to release the restraints for on-orbit operations.

The automated restraint illustrated shows a roller latch securing a strap on a solar panel bar to a spacecraft structural member. The automated pin puller operation allows an over-center linkage mechanism spring to operate, removing the roller latch from the retention strap; this allows the solar panel bar to be elevated to its operating position. Actual cost data for this device was obtained from a Rockwell contract.

The manual latch assembly alternative for the solar panel application is shown on the right-hand side of the figure. This illustrates a comparatively simple lever with a latch release button designed for operation by the astronaut wearing a typical space suit glove. Cost estimates for this assembly were based on materials and design factors.

The EVA alternative design provides a significant cost saving. A minor weight saving was also estimated. The major cost savings occur from the simplification of the mechanism itself, the elimination of power and monitoring electrical circuits, and the simplification of the development testing and acceptance testing procedures.



	AUTO	EVA
DDT&E	54	8
UNIT	20	5

Figure 2-11. Solar Panel Latch Designs

The high gain antenna latch consists of the following components:

Latch - pin type

Clamp - spring

Unlatch - pin puller/pyro

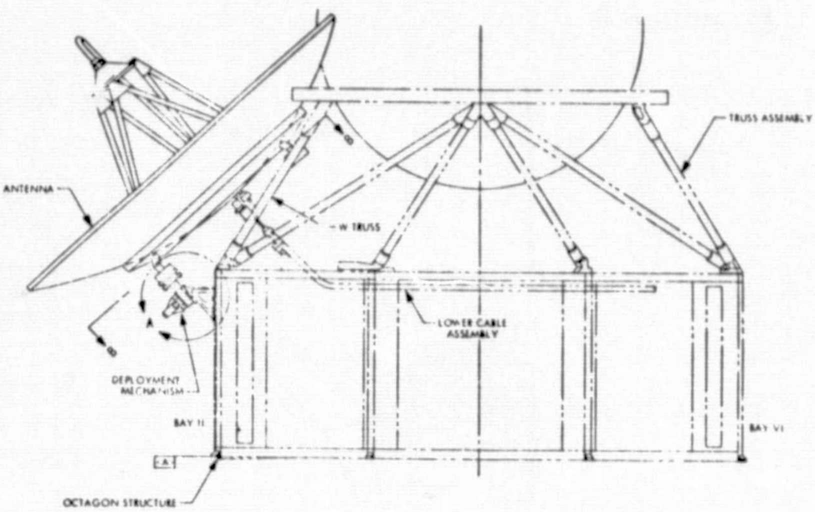
Release - spring

Complexities - Belleville washers

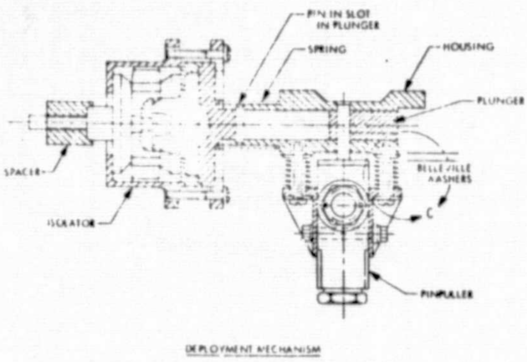
Gimballed or steerable antennas conventionally are restrained during boost to reduce or remove loads on the control mechanism. The flight-qualified automated design in Figure 2-12 provides a pin puller mechanism whose operation separates the antenna attachement to the spacecraft housing and thus allows the antenna freedom of movement. Project source data were used to establish the costs shown for the automated design. The manual concept latch alternative provides a simple over-center handle operated mechanism to hold a restraint rod. The locking pin provides a secure attachment. When released, the T-bar ensures freedom of movement for the antenna. The manual concept costs were estimated on the basis of CER data for mechanisms of comparable materials and complexity and represent about 93 percent savings over the costs for the automated version.

● NOMINAL COST - $K

	BASELINE	EVA
DDT&E	82	6
UNIT	30	2



● BASELINE MODE



● EVA MODE

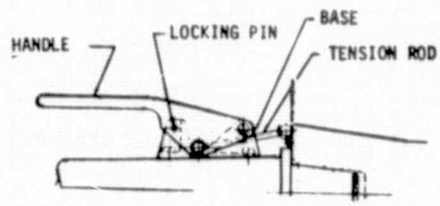
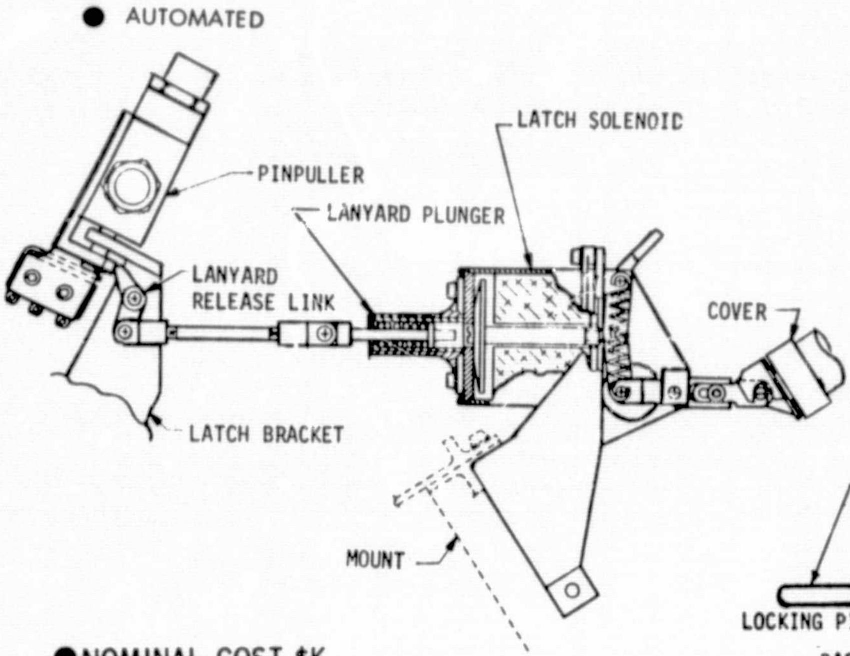


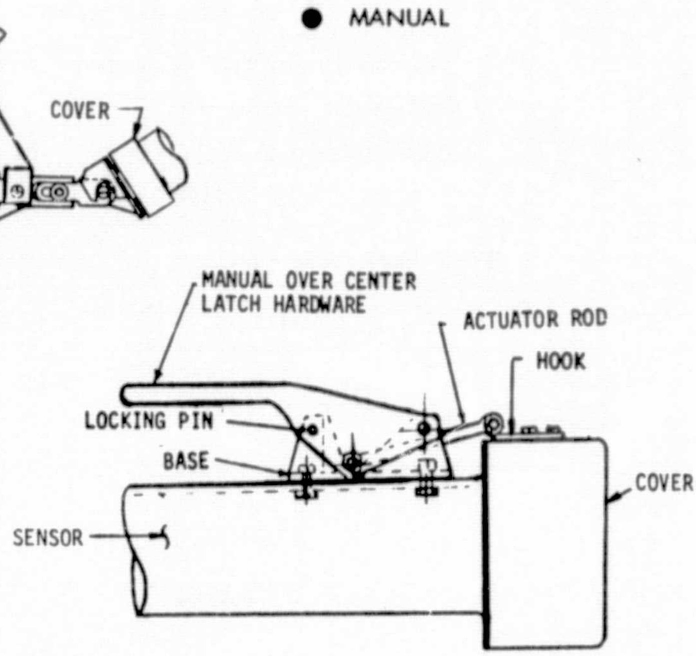
Figure 2-12. Antenna Latch Designs

Because of the unique deployment requirement of this system [3.2 cm (1.25 in.) linear displacement], EVA equivalent to this mechanism is completely different from the solar panel latch. It is a very simplified mechanism substituting for the latch, clamp, and release functions of the remote-operated design. The Belleville springs used to damp the pin puller shock are not required. Reliability qualification costs are minimized. The pin-puller design is one-shot, untestable, while the manual design can easily be latched as well as unlatched.

Various concepts for sensor cover latches have been devised. An example of a sensor cover latch mechanism utilizing a solenoid and lanyard assembly appears in the JPL technical report referenced on page 2-18 and is illustrated in Figure 2-13.

The mechanism is of the multiple application type; that is, it may be operated and reset any number of times during checkout or operation. The system is self-locking in that it has a snap-over-center position when locked. To operate the systems, power is applied to a solenoid driving a plunger pushing the locking device to the unlocked position releasing the cover. A back-up mechanism using a mechanical pin puller is included as part of the system





●NOMINAL COST $K

	AUTO	EVA
DDT&E	26	1.0
UNIT	10	0.2

REF: JPL REPORT 32-832

Figure 2-13. Sensor Cover Latch Designs

should the solenoid fail. The pin puller, upon activation, releases a spring-driven lanyard plunger which drives the solenoid pin as discussed above.

The sensor cover latch consists of the following components:

Latch - hook/pin

Clamp - over-center toggle

Unlatch - spring

Release - solenoid

Complexities - backup release lanyard

The EVA device, a manually positioned over-the-center latch, is highly simplified compared to the automated concept. The simplicity of the manual latch, compared to the automated is emphasized in the cost data comparison.

With an estimated weight of 0.2 kg, the manual device is significantly lighter than the 1.7 kg weight of the automated concept. Contamination considerations for EVA removal of sensor covers are discussed in Section V.

A scan platform latch assembly, Figure 2-14, consisting of the following elements, was also examined for typical characteristics:

Latch - T-bar

Clamp - Pneumatic pressure

Unlatch - Spring/pressure bleed/release spring

Release - pyro valve

Complexities - manifolding, piston sizing and return spring sizing to establish unlatching sequence

● NOMINAL COST - $K

	BASELINE	EVA
DDT&E	28	6
UNIT	9	2

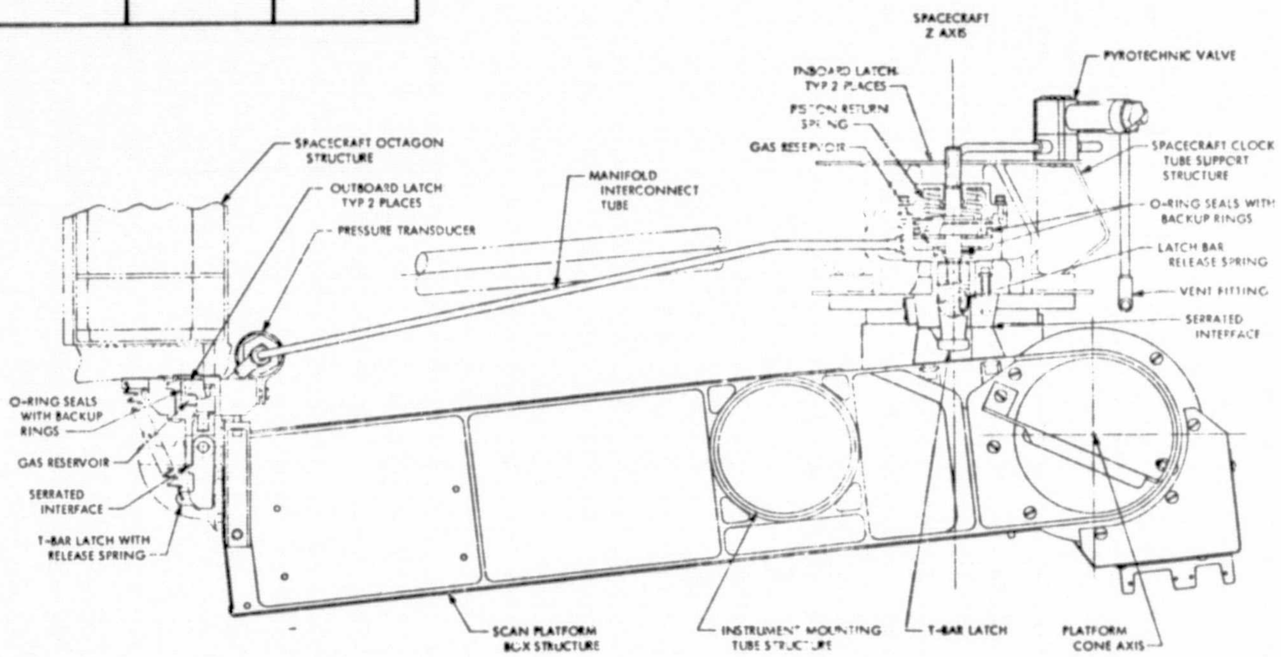
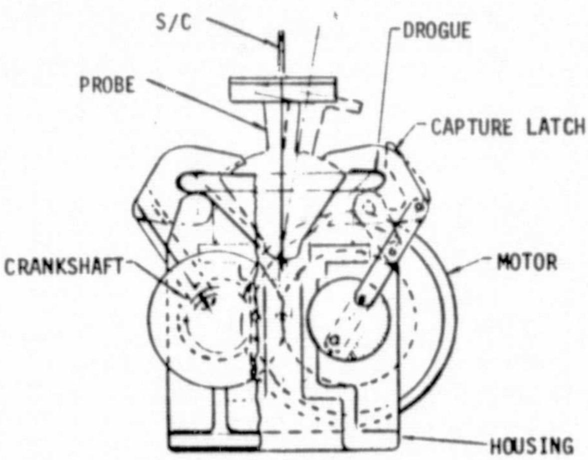


Figure 2-14. Platform Latch Design

An EVA equivalent to this latch mechanism could be a manual release toggle on the axis-pin of the present pneumatic cylinder in lieu of the pneumatic system and pyro valve. A mechanical interlock would be required to assure the proper sequencing. However, the simplest design, as used in this study, would be the same as shown for the antenna latch. Weight savings was estimated at 1 to 2 kg.

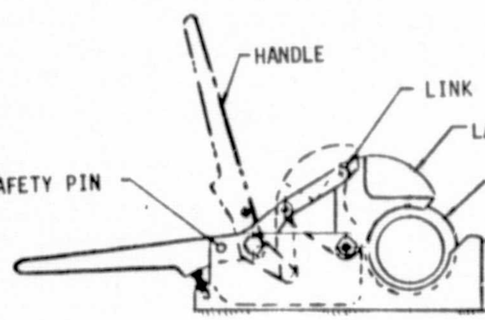
Payloads not using standard retention fittings; i.e., payloads whose outer diameter is too small to interface with the standard bridge fittings, must provide for special retention during boost, entry, and landing phases of the mission. Retention latches should provide for capture as well as release of the payload to ensure either planned or contingency retrieval. The automated concept shown in Figure 2-15 is one developed on an earlier Space Division contract for the EOS flight support system. It is based on the mechanism used for docking in the Apollo program. The design uses motor-driven capture latches to secure the spacecraft probe after docking or to release the probe during separation operations. The cost estimate for a mechanism of this type to be developed for future applications would be $68,000 for DDT&E and $25,000 first unit recurring costs.

- AUTOMATED



REF: ROCKWELL EOS/FSS CONCEPT

- MANUAL



- NOMINAL COST $K

	AUTO	EVA
DDT&E	68	11
UNIT	25	4

Figure 2-15. Payload Retention Latch Designs

A manual mechanism for EVA operations for this payload latching function is shown in the right half of the figure. Here a lever-operated, over-center mechanism would operate links to secure a trunnion-type cylindrical spacecraft fitting to the base attached to a payload orbiter support system. DDT&E and first unit costs represent about 83 percent savings compared to the automated design. The number of units required for each spacecraft application might vary with individual designs but would typically be 4. The cost savings for the total program applications would be substantial.

Test programs have historically been extensive and costly for remotely actuated devices such as the latches discussed previously. A case in point is the Science Cover and latch test program performed by JPL on Mariner IV spacecraft.[1] Qualification of the latch and cover assembly prior to spacecraft delivery consisted of a series of environmental and performance tests. Briefly, these tests were conducted in the following sequence: (1) performance testing where the solenoid was cycled in a vacuum at various temperature extremes, assembled to the latch and recycled, then assembled to a cover and repeatedly unlatched in a vacuum using both actuator and lanyard backup; (2) subjecting the assembly to the general environmental specification consisting of humidity, storage, shock, static acceleration, low frequency vibration, and high frequency complex wave vibration; and (3) repeating the above performance tests for the completed assembly.

In addition, although not considered a qualification test, one spare solenoid and one complete assembly were subjected to a vacuum-temperature life test with the chamber environment held at 130 F and approximately 10^{-6} mm Hg. The solenoid was cycled once a day against a plunger preload with an end-of-stroke indicator to verify actuation. The science cover assembly with a separate solenoid and latch was allowed to soak for varying time periods from 15 to 30 days and then actuated. At the completion of the 180-day test cycle no failures were noted.

Performance of the assembly during the initial qualification tests was hampered by fabrication problems with the honeycomb plate. The lack of proper insert bonding exhibited itself during the first high-frequency complex wave vibration where the inserts proceeded to work loose allowing high excursions and eventual destruction of the cover hinges and latch fittings. Following the incorporation of properly fabricated hardware, qualification proceeded with no failures noted in any developmental or flight hardware test.

Table 2-1 summarizes test data for the latches reviewed.

2.2.2 Solar Panel Deployment Drives

Although differences occur based on configuration and solar panel sizes, five of the nine representative spacecraft have solar panel deployment devices which could be actuated in one of three ways:

1. Shuttle activated by attachment to the manipulator arm end effector

2. Remote actuated

3. EVA deployed

In a preliminary design phase such as performed in this study, the assessment of complexity of any remote actuator cannot be undertaken, because variations in the final designs are nearly unpredictable. This assessment is meant to be a reasonable average. The same holds true for EVA and the manipulator interface.

Table 2-1. Test Programs for Remote Operation Latches

Latch Type	Test Programs
High gain antenna latch	Operational verification in vacuum pin puller with and without Bellevilles Vibration environmental test
Science cover latch	A series of environmental tests Vacuum Solenoid Solenoid with latch Solenoid with latch & cover Mechanical environments Latch assembly Complete assembly Vacuum-temperature life test Solenoid assembly Complete assembly
Scan platform latch	Many early tests on materials and design leak tests 1200 psi hold for 6 months
Solar panel latch GPS	Individual latch - functional tests under load and 50 percent overload. Static stress testing. Installed latch system tests - operations checks with a mechanical (ground) and electrical (flight hardware) pin-puller. Tests before and after each thermal, vacuum, acoustic, and environmental condition for every functional mode; e.g., dynamic, spin, etc.
Payload retention latch	No information

The evaluation of the remote actuator is based primarily on extrapolation of data for an electric motor actuator submitted by Hughes for a military satellite hardware contract.[1] The complexity is equivalent to actuators available from Lockheed and Ball Brothers Research Corp. A spring motor actuator design based on data available on the JPL Viking actuator was also reviewed. The evaluation of a manipulator arm attachment is based on the design from a payload interface study[2]. The EVA design concept was generated for this study.

The detailed design in Figure 2-16 represents a typical solution to solar panel latching, deployment, and orientation mechanisms. It is a space hardware vendor (Lockheed) design.[3] In applying this type of design to any new spacecraft program, costs are incurred not only in the actual hardware procurement but in designing and developing the system-unique characteristics. Size of the array, location on the structure, size and routing of the wire bundle, weight allocation, launch envelope, boost dynamics, spacecraft pointing orientation requirements, etc., must all be analyzed and specified. As a result, essentially a new development is required for each unique spacecraft program. Prototype or flight hardware must undergo significant thermal vacuum and other qualification or operational testing, all adding to the significant costs of such automated designs.

The electric drive and the spring drive system are assessed and compared in Table 2-2.

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(1) Proposal for Space Segment of the Global Positioning System, Phase I (Validation Phase), April 1974.

(2) Rockwell SD 72-SA-0194, Shuttle/Typical Payload Interface Study

(3) Pictorial Review of Lockheed Capability in Solar Photovoltaic and Battery Electrical Power Systems, LMSC-A834772, 18 April 1967.

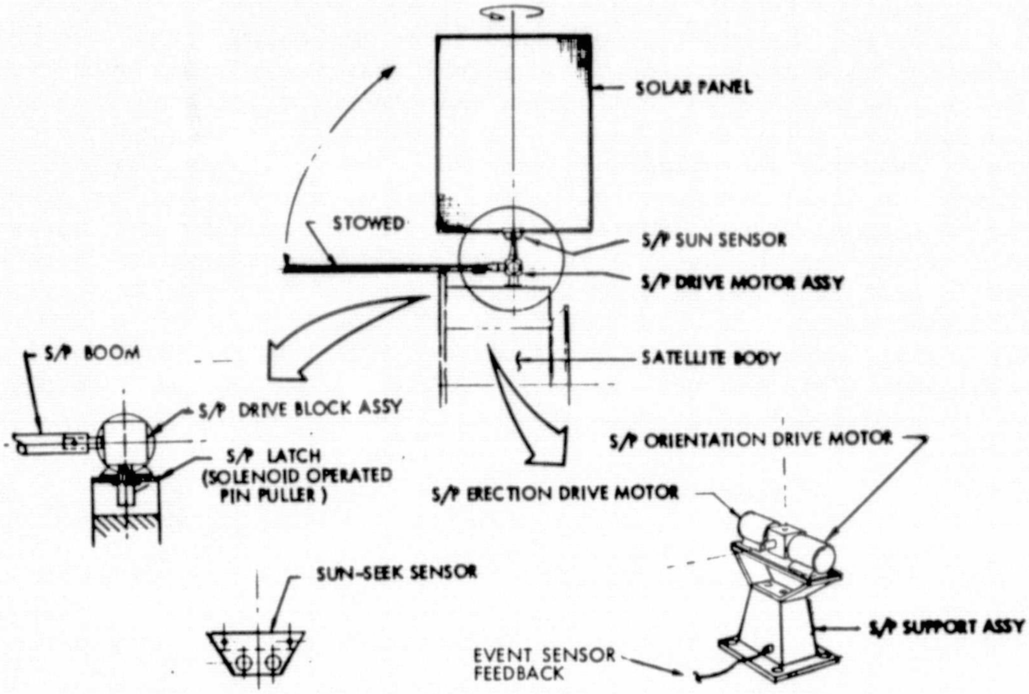


Figure 2-16. Automated Solar Panel Design Concept

Table 2-2. Remote Actuated Solar Panel Comparisons

Assessment	System Type: Electric Drive	Spring Drive
Cost: first unit	\$40,000	\$10,000
Cost: admin, eng., qual.	\$109,200	\$27,300
Cost: total one unit	\$149,200	\$37,300
Weight: one unit	6.34 kg (14 lb)	1.8 kg (4 lb)
Power: max.	200 watts	28 watts
Power: consumed	1.6 whr	0.04 whr
Volume	0.0084 m^3 (0.3 ft^3)	0.00056 m^3 (0.02 ft^3)
Adjunct equipment	Electric control sys. Control panel Operation sensor talkback Uplink data channels	Electric control sys. Control panel Operation sensor talkback Uplink data channels

An alternative EVA-oriented design, Figure 2-17, can eliminate both the erection motor and the remotely operated latch mechanism. This not only eliminates the hardware elements, the signal interface, limit switches, talkback, etc., but all of the design development and testing associated with them. In this concept, the solar array is carried to orbit stowed separately from the spacecraft, manually installed and fastened. The design is simple, failure-proof, and, except for final connector alignment, has no close tolerance likely to be affected by thermal-vacuum conditions. The EVA design also eliminates the necessity of bending the solar array wire bundle. Considerable costs have been incurred in past programs in overcoming problems with thermally stiffened wire bundles during deployment. An additional EVA application would be to manually install adequate solar panel area to preclude the need for the orientation mechanism. This was not evaluated in the study, and would involve a trade between the additional solar cell area costs versus cost of the orientation mechanism.

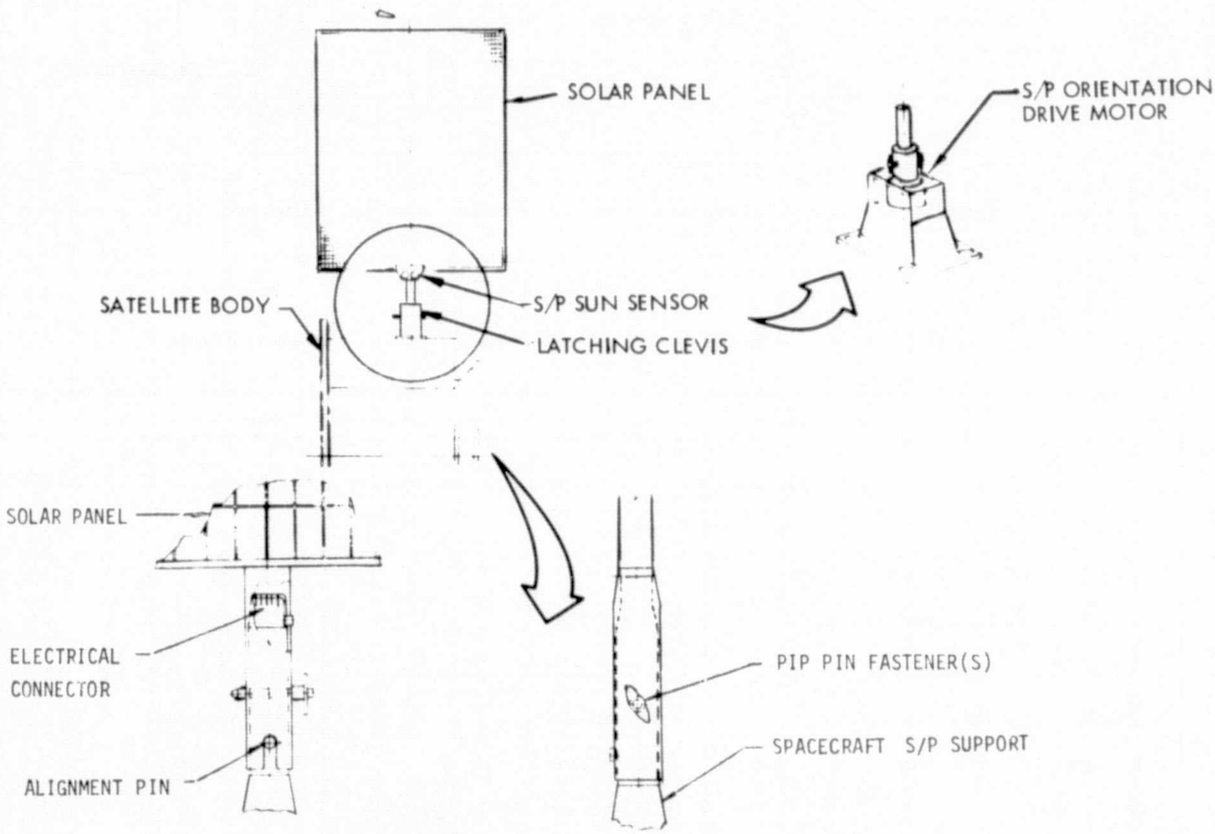


Figure 2-17. EVA-Oriented Solar Panel Design Concept

The EVA work aids to perform installation of the manual design shown previously can normally be attached to the payload retention frame. The restraint unit concept illustrated could be folded out to improve reach/access, and includes a rigid waist restraint to stabilize the crewman and react the installation forces. The stowed location of the solar panel is adjacent to the work station. Using manual installation for payloads with an upper stage requires an analysis of the thrusting loads involved. In some cases, additional structural strength is required to ensure that the array can be carried to the higher orbit in the extended position. However, the additional structural cost is considerably less than the erection device. This design also simplifies the on-orbit replacement of the solar panels for payloads with planned on-orbit maintenance. The payload illustrated in Figure 2-18 is shown installed on a Spacelab pallet section, which may be a suitable approach for boost retention of smaller diameter spacecraft.

- MAGNETIC FIELD MONITOR

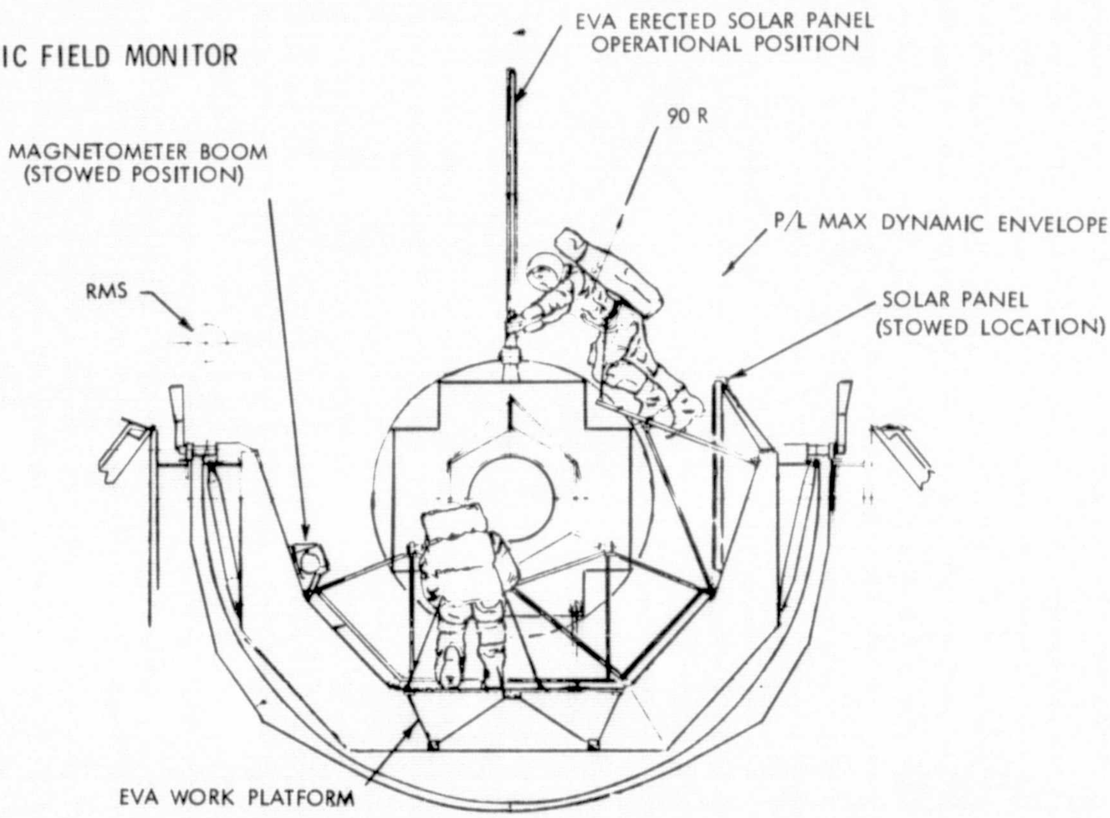


Figure 2-18. Typical Manual Installation - Solar Array

The Shuttle Remote Manipulator System (RMS) alternative for solar array deployment (as well as removal and installation) has been previously studied in conjunction with EOS Flight Support System studies. Figure 2-19 illustrates a design concept based on using a rotating end effector and interfacing spacecraft fitting which would permit various operations. In the case of the EOS, this could include unfolding segments of the array, erecting the assembly (as illustrated) and removing/installing the assembly. Generally, characteristics are unique to spacecraft programs; however, commonality of the end effector has potential for total cost avoidance.

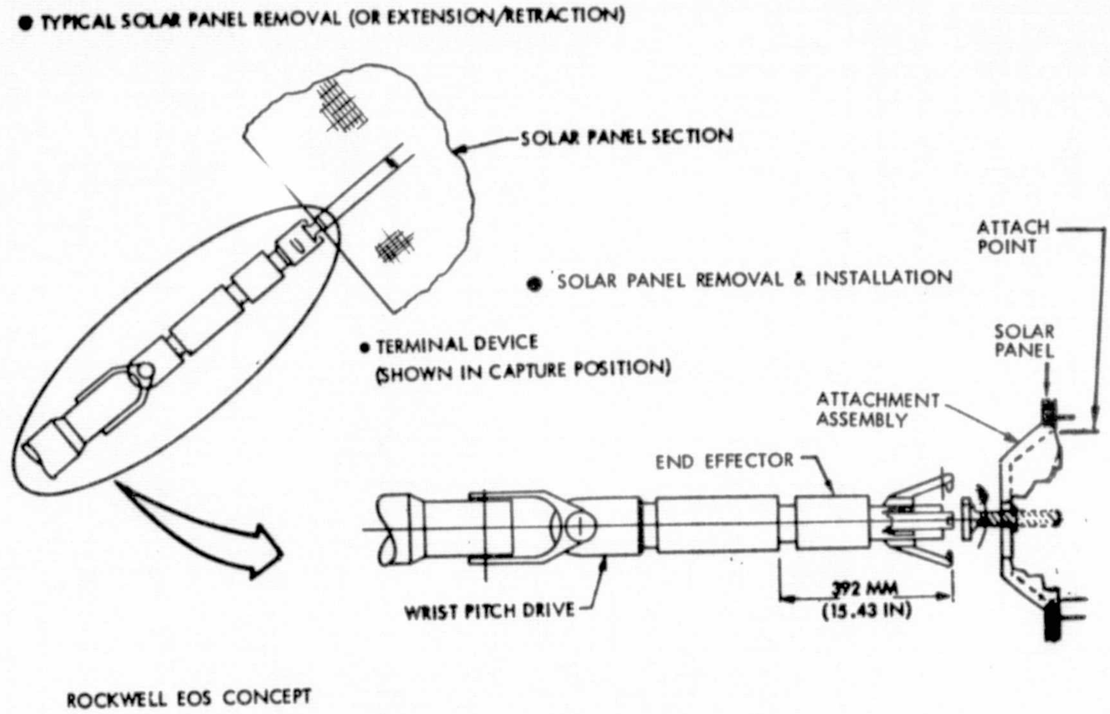


Figure 2-19. RMS-Solar Panel Design Concept

Summary. Comparing the characteristics of mechanized, manual, and RMS solar panel design concepts indicates that weight savings occur in the RMS and EVA modes but do not prove to be significant in view of overall payload weights. The cost data in Table 2-3 for automated equipment are lower bounds and could be significantly higher, especially for folding configurations as required on larger spacecraft. The savings for manual configurations are significant. Cost differences occur in all aspects of program and recurring costs, including increased design complexity, project engineering, remote control/talkback, Q&RA, ground testing, manufacturing tolerances, etc. It should be noted that unit costs apply to the number of panel assemblies per spacecraft as well as to the number of spacecraft. An important advantage in the EVA oriented design is minimal potential design failure modes.

Table 2-3. Mechanical Elements Analysis - Solar Panel Summary

MECHANISM CONCEPT OPTION	NOMINAL WT. (KG)	NOMINAL COST ($K)	ADVANTAGES/ DISADVANTAGES
SPRING-MOTOR DEPLOYMENT (JPL VIKING DATA)	2.0	DDT&E: 30 UNIT: 10	LOW WEIGHT AND COST
√ ELECTRIC MOTOR ACTUATION (LOCKHEED CONCEPT) NOTE: ADD 20% FOR UNFOLDING	7.0	DDT&E: 110 UNIT: 40	REDUNDANCY DEPLOY AND RETRACT CAPABILITY
RMS ACTUATED DEPLOYMENT MECHANISM + SPECIAL END EFFECTOR	3.2 2.4	DDT&E: 27 UNIT: 10 DDT&E: 31 Unit: 9	LOW WEIGHT/COST NO REDUNDANCY PRECISION OPERATION
MANUAL INSTALLATION	2.0	DDT&E: 9 UNIT: 5	LOWEST WEIGHT/COST NO FAILURE MODE
√ SELECTED FOR COMPARISON TO EVA MODE			

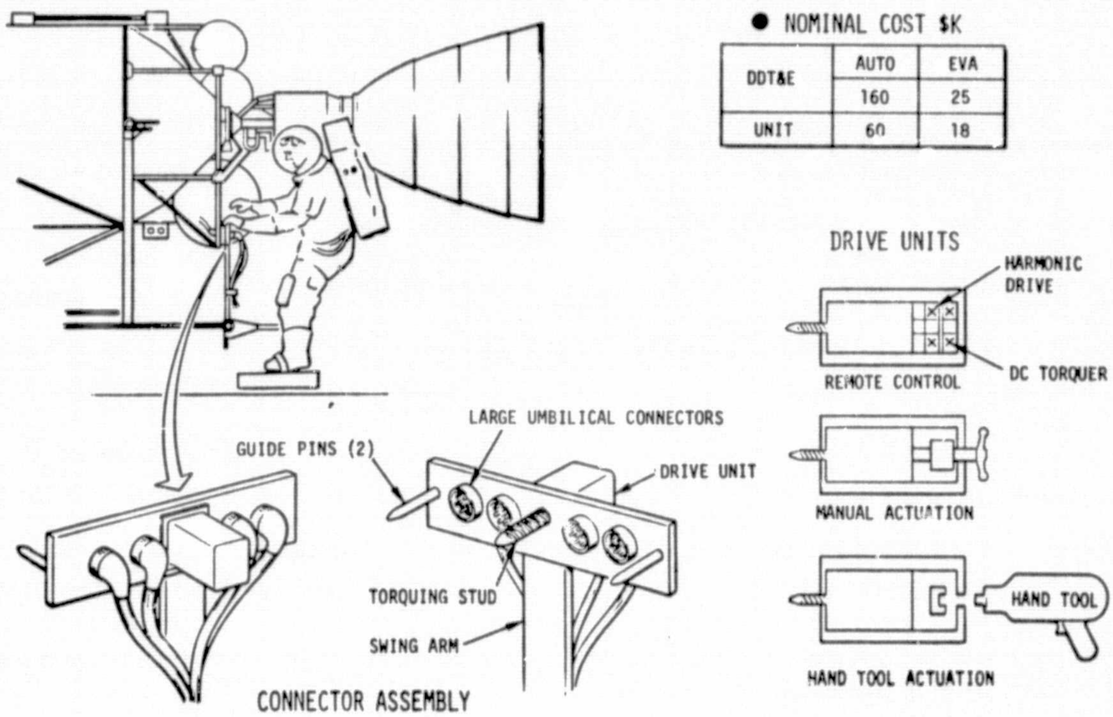
The two-way electric motor actuation concept was selected for this study in that: (1) all retrievable or reusable payloads require it, and (2) expendable payloads can only be "rescued" from early failures with two-way operation. Reference contingency options, Figures 1-2 and 1-3.

2.2.3 Large Umbilical Connector Concepts

There is no practical historical background on two-way remote umbilical connectors. The separation type of umbilical has been flown but is of the guillotine type. To develop comparative data, requirements imposed on the design and mechanization were examined.

For simplicity the umbilicals were considered in two groups: (1) those with many pin connections, where required forces are of large magnitude, and (2) those which are small in magnitude. The larger the connection requirement, the greater the force application. Several options are available to perform the connection/deconnection function. The options include the application of a remote-controlled device, a manual actuator, or a motorized hand-tool actuator. For all large sizes, an alignment indexing system is required; whereas, small connectors can be aligned with a built-in keyway. Figure 2-20 illustrates one concept for umbilical connection.

The size of connector and the type of forces involved will dictate concept selection. Only nominal cost data are shown, based on detailed estimates of the hardware involved in the automated mode versus manual. High costs of the



● NOMINAL COST $K

	AUTO	EVA
DDT&E	160	25
UNIT	60	18

Figure 2-20. Large Umbilical Connector Concepts

automated concept include remote control/talkback equipment, as well as high costs associated with testing and qualification which are largely omitted in a manual concept. It should be noted that the automated mode would require, in addition to the elements shown, two-way motor drives for the swing arm, and remote two-way latches to restrain the swing arm during boost and entry when not engaged with the payload. It should also be noted that each spacecraft will require a minimum of one signal connector (plus Shuttle power when required) with grounding. Additional umbilicals may be required if separate, redundant critical circuit paths are required or for any fluid interfaces which might be used for top-off on delivery, refill during servicing, and dumping/venting during abort or entry.

From a functional analysis standpoint, the execution of an umbilical connection and disconnection can be broken down into a series of discrete sequential operations. The operations may be listed as follows:

1. Prealignment

   a. Interrogate location
   b. Verify
   c. Unlatch
   d. Verify
   e. Engage alignment
   f. Verify

2. Umbilical attachment

a. Operate torquer
b. Verify pin continuity
c. Latch
d. Verify

3. Umbilical disengage

a. Deadface
b. Verify
c. Unlatch
d. Verify
e. Operate torquer
f. Retract
g. Verify
h. Latch
i. Verify

The operations listed may not be performed as individual steps or by separate equipment. Several of the operations may be combined or eliminated, but the effect of each operation must be accounted for.

The simplicity of an umbilical system will depend in part on the extent to which the operations are combined and the extent to which the effect of an operation is inherently contained in the prior operation.

The four major operations are defined as follows.

1. Prealignment attachment

   The establishment of a location reference from which the connection mating may be performed. This reference should be as close as practical to the structure of the fixed half of the connection. In the remote case, it should be a part of the actual fixed half structure. The satellite mounting fixture or the Shuttle payload bay is not a sufficiently accurate reference. In the EVA case, the mounting fixture or payload bay may be adequate.

2. Umbilical attachment

   The physical mating of the two halves of the connector system. This is accomplished after operation 1 is established.

3. Umbilical retraction

   The physical separation of the two halves of the connector system.

4. Removal

   The release of the umbilical system to the status prior to operation 1. This is accomplished after operation 3 is established.

Verification of operations in steps b, d, and f by event sensing switches is required before initiating the succeeding step.

CASE I

A remote operated umbilical system, large scale (many connections or electrical plus pneumatic), would be made up of the following functional parts.

1. A payload holding fixture and an umbilical positioner assembly, each fixed to the payload bay structure to establish a rough tolerance prealignment position.

2. A tray assembly on the positioner which translates or rotates into the proximity of the payload. The tray assembly is positioned by a motor actuator, which is, part of the positioner base assembly. The tray assembly carrys with it two functional subassemblies: First, an alignment subassembly which indexes to the payload with a wide tolerance index, such as a tapered pin, and latches or locks the tray assembly to the payload. The latch is either locked or unlocked, or both, by a motor actuator, part of the alignment subassembly. Second, a connector subassembly which, after locking of the alignment subassembly is in a close tolerance position to insert or connect the two havles of the connector system. The insertion is performed by a motor actuator, part of the connector subassembly, acting against the payload structure.

3. A single structure portion of the payload acting as a passive interface to the alignment subassembly and the connector subassembly.

4. Variations - the umbilical positioner must be compliant to the extent that precise mating will take place. Either the tray assembly is sufficiently compliant to carry both the alignment subassembly and the connector subassembly or the connector subassembly will be carried as a part of a compliant alignment assembly.

   Where the payload interface structure is sufficiently rigid, the tray assembly motor actuator might serve the function of the alignment subassembly latch.

An equivalent EVA operated system would be comprised of the following functional parts.

1. An equivalent holding fixture and positioner assembly.

2. An equivalent tray assembly, manually positioned; an equivalent alignment subassembly manually latched; and equivalent connector subassembly.

3. An equivalent payload interface.

CASE II

A remote operated umbilical system, small scale (single electrical or pneumatic connector) would be made up of the following functional parts.

1. A payload holding fixture and an umbilical positioner assembly. The positioner may be an integral part of the holding fixture.

2. A tray assembly on the positioner which translates or rotates into proximity of the payload; probably a swing arm, 20-30 degrees travel. The tray assembly is positioned by a motor actuator, part of the positioner assembly. The tray assembly carrys with it only one subassembly which performs both the alignment and insertion functions. The alignment actuation can be performed by the positioner motor actuator because of the low force levels involved. The alignment is effected by tapered pins or by the bodies of the two connector halves. The subassembly has sufficient flexibility to assume an aligned position. The connector insertion is performed by a motor actuator acting against the payload structure.

3. A passive interface structure of the payload. This may be the body of the payload connector half.

An equivalent EVA operated system would be comprised of the following functional parts.

1. A static storage fixture for the unconnected cable and connector.

2. An alignment/insertion assembly at the end of the cable. The assembly would provide an alignment latch (automatic latch-manual unlatch) equivalent to the lock-up function of the positioner motor actuator in the remote operated system. The latch may be an integral part of the insertion lever mechanism. The assembly would provide an insertion mechanism, probably equivalent to the lever/toggle mechanism used on patch panel connectors.

3. A passive interface structure of the payload.

2.3 TASK-TIME DATA

Task-time data building blocks were equally important to the analysis of representative payloads as design data building blocks. Saving costs by designing for EVA activities would be of little use if the time required were to exceed Shuttle support capabilities or seriously impact payload flight schedule. The figure of importance is, of course, the delta time resulting from EVA compared to remote controlled operations. The factors primarily influencing these times are:

1. Length of time necessary to prepare for payload operations

2. Availability of a starting time within the constraints of the Shuttle mission

3. Time lapses in proceeding from one operation to another due to movement rates, clearances, and accessibility

4. Potential for concurrency of operations versus the necessity of series activities

The first three factors are dealt with in this section. The sequencing of activities was analyzed in conjunction with preparation of integrated timelines as discussed in the next section.

2.3.1 Payload Operations Preparation Time

Both EVA and remote operations require preparatory activities before direct payload operations can begin. In the case of remote controlled operations, preparation consists primarily of panel checks and set-up of the payload and RMS control stations. Neither station has been defined to a design level as yet, and in the case of the Payload Station (PS), the configuration may vary with each payload. However, in order to establish a reasonable level of accuracy, a variety of sources were reviewed. These include:

1. Apollo experience

2. JSC RMS simulator control station experience

3. Rockwell SD EOS flight support system demonstration control station experience

4. Preliminary PS concepts from SSPD, studies such as McDonnell-Douglas "Shuttle Orbital Applications/Requirements" studies and in-house analyses.

A resultant consensus of data indicated that approximately one-half hour with two men working concurrently at the two stations would be required.

In considering EVA preparation, the primary consideration is the time involved by the EVA crewman to suit-up, prebreather, and perform airlock operations. The prebreathing time is a variable as a function of suit pressure level subsequent to departure from the orbiter 14.7 psi cabin. Figure 2-21 compares the preparation time requirements between an 8 psi and 3.7 psi spacesuit, prior to egress from the orbiter airlock and entry to the orbiter payload bay. The use of the 8 psi suit is estimated conservatively to require approximately 2 hours of preparation time compared with approximately 3.5 hours for the lower pressure garment for routine operations. The major influencing factor is that of the oxygen prebreathing required for approximately 1.5 hours prior to EVA equipment preparation, suit donning, final equipment checkout, and the airlock operations. It should be noted that certain other crew activities can be performed during the early prebreathing period by use of portable oxygen masks.

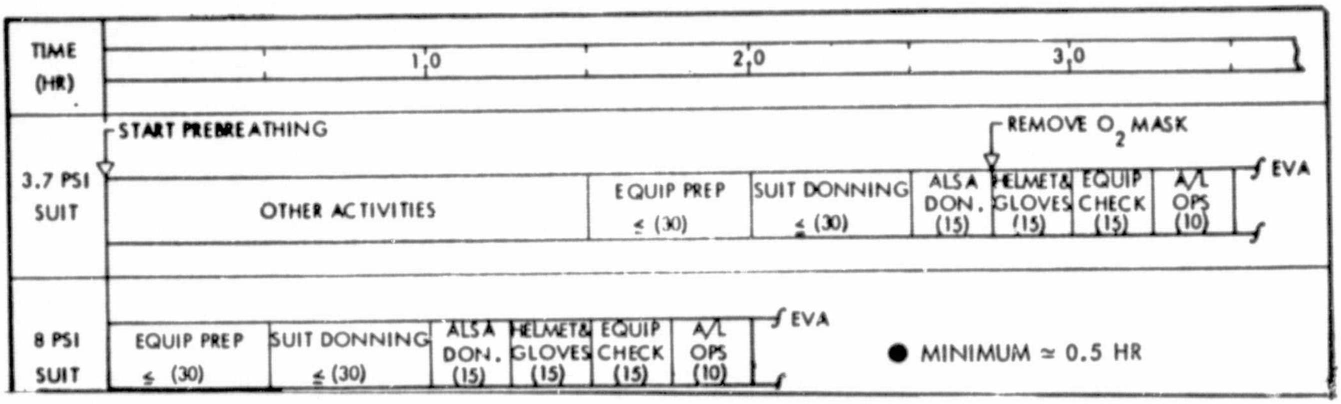


Figure 2-21. EVA Preparation Time Typical Routine Timelines

The 3.5 hours represents the capability planned in the current orbiter/airlock design and is the study baseline. The current Shuttle baseline plans are to provide an EMU at 4 psi with integral life support backpack and low mobility lower body assembly. Baseline provisions will include a manned maenuvering unit (MMU) for EVA free-flight operations. Some potential exists for advanced technology equipment which constitutes two issues involved with EVA. One of these issues relates to quick-reaction time, primarily relating to the higher pressure EMU used to preclude pre-breathing. Analyses performed in the study indicated improved operations or increased cost savings could be attributed to quick reaction; e.g., increased experiment time in an EVA mode and response to time-critical contingencies. Paragraph 2.4.2 describes the contingency analysis. The second issue, overall mobility, was not evaluated in detail. However, in the process of examining the crew time sequences, especially for crewman translating through a maze of sortie payload experiments, his visibility and mobility should be the best possible to preclude damage to equipment or the EMU.

2.3.2 Shuttle Mission Timelines

Payload operations are constrained by priority Shuttle mission events. For the purpose of this study, two timelines were defined for two reference Shuttle missions which can be described as Near Earth Orbit (NEO) and High Earth Orbit (HEO). An orbit of 200 nmi was chosen as the approximate dividing altitude. Starting time to prepare spacecraft for separation, to dock to spacecraft for retrieval or servicing, or to initiate sortie experiment operations is dependent on Shuttle mission timelines. Launching the orbiter into either of the above orbits results in different basic timelines, Figure 2-22. The Mission Data Book[1] was used as the reference document to develop the NEO and HEO basic timeline windows. In both cases a substantial amount of time early in the mission is dedicated to orbiter activity. That is, for the establishment of the selected orbit and general orbiter configuration. Also, in both cases the crew has a scheduled sleep period.

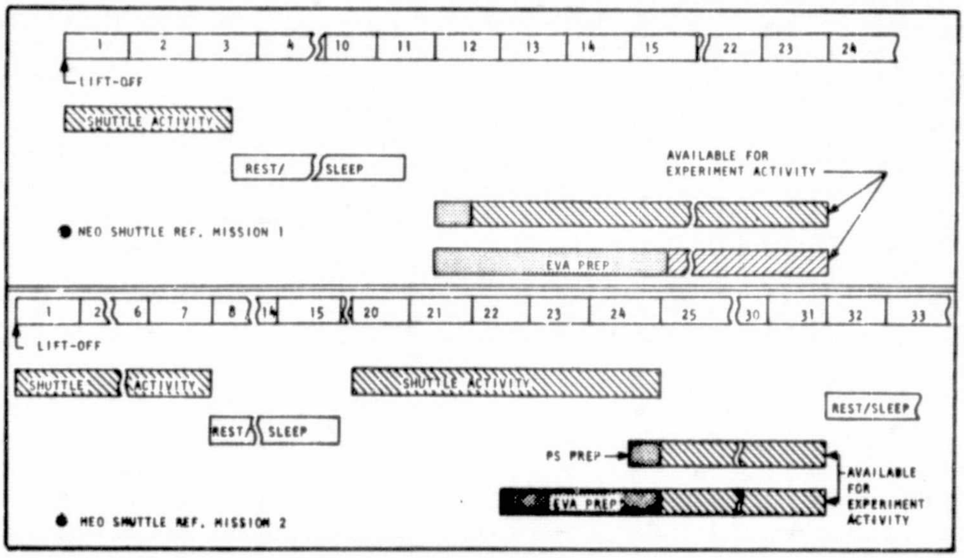


Figure 2-22. Basic Timelines, Shuttle Launch Phase

In the NEO case, the crew may begin experiment preparation and operations in either the automated or EVA mode at the twelfth hour, ground elapsed time (GET). On the basis of a nominal 12-hour crew work period and with 0.5 hour of preparation, about 11 hours of payload operations time is available. In the EVA mode, with 3.5 hour of preparation (including pre-breathing), only about 8 hours remains for experiment activity.

For the orbiter reference mission 2 (HEO), actual experiment operations can begin starting with the 25th hour, GET. This mission required a second orbiter activity period during which automated or EVA preparation can take place. During this time the OMS is fired several times and the IMU is aligned following each firing. Thus, experiment activity or EVA is limited to the preparation phase only.

(1) Rockwell, Space Division, SD 72-SH-0095-1, dated 9-3-74

It is possible in this mode to initiate EVA as early as automated operations since either form of preparation can precede the completion of Shuttle activity. In this case, about 7 hours of the shift remain for payload operations. The representative payloads were about equally divided between the two types of missions.

2.3.3 Automated Devices - Basic Movement Rates

A key ingredient in the development of baseline integrated timelines is the performance of automated deployment devices. Data for three such automated devices were used in the study. One important performance parameter is illustrated in Figure 2-23.

The Shuttle Remote Manipulator System includes a 15.2 m (50-ft) boom mechanism having a maximum diameter of 0.38 m (1.25 ft) and 3 flexible joints. It has a maximum maneuvering capability of placing a 29,484-kg (65,000-lb) payload 7.6 m (25 ft) above the orbiter centerline and over the cabin area. The exact time for this maneuver is yet to be determined; however, the tip speed has been set at a maximum of 0.6 m/sec (2 fps) unloaded and something less for loads up to 453.6 kg (1000 lb).

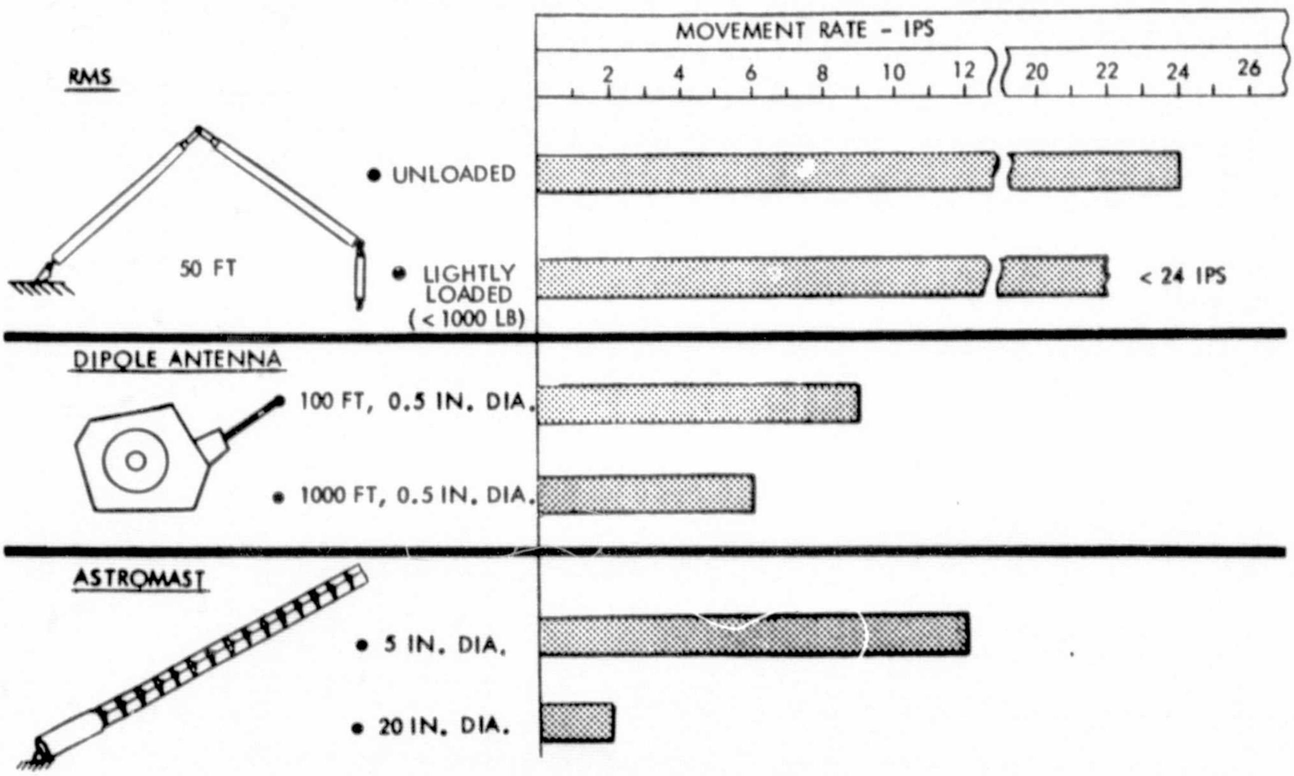


Figure 2-23. Automated Devices, Basic Movement Rates

STEM[1] Device - the longest dipole antenna among the representative payloads is used on a low-frequency experiment on the AMPS sortie payload. The experiment requires deployment of two 304.8 m (1000-ft) antennas. One such unit has an extraction/retration rate of 0.15 m/sec (6 in./sec). STEM devices have a number of applications among the payloads.

Astromast[2] Deployment. The AMPS sortie payload also has a requirement to deploy two 50 m (164 ft) booms with the ability to be articulated in two directions with substantial masses mounted on the free ends (including two smaller Astromasts). The 50 m (164-ft) units are deployable at a rate of 0.05 m/sec (2 inches per second) or 16.5 minutes to deploy. Astromast elements occur frequently in both sortie and automated spacecraft designs.

2.3.4 Skylab EVA Task Times

Extra Vehicular Activity has been a significant operational element of all Apollo and Skylab manned space programs. The method used to develop basic data for preparing integrated payload EVA timelines included examination of prior data, particularly from Skylab.

To show examples of both preplanned and contingency activities that have been performed to date, reference is made to an EVA on Skylab (SL-4, EVA-1, MD-7)[3] shown in Figure 2-24.

Less than 2 hours of EVA activities were planned. However, due to failures and other contingencies, the EVA extended into the seventh hour. The illustrated timeline contains 5 planned tasks and 7 unplanned activities. An important lesson learned from Skylab is that generally trained EVA crewmen can perform a variety of unplanned tasks with a minimum of special tools and training. These data were used to establish credible task times in the representative payload operations analysis discussed later.

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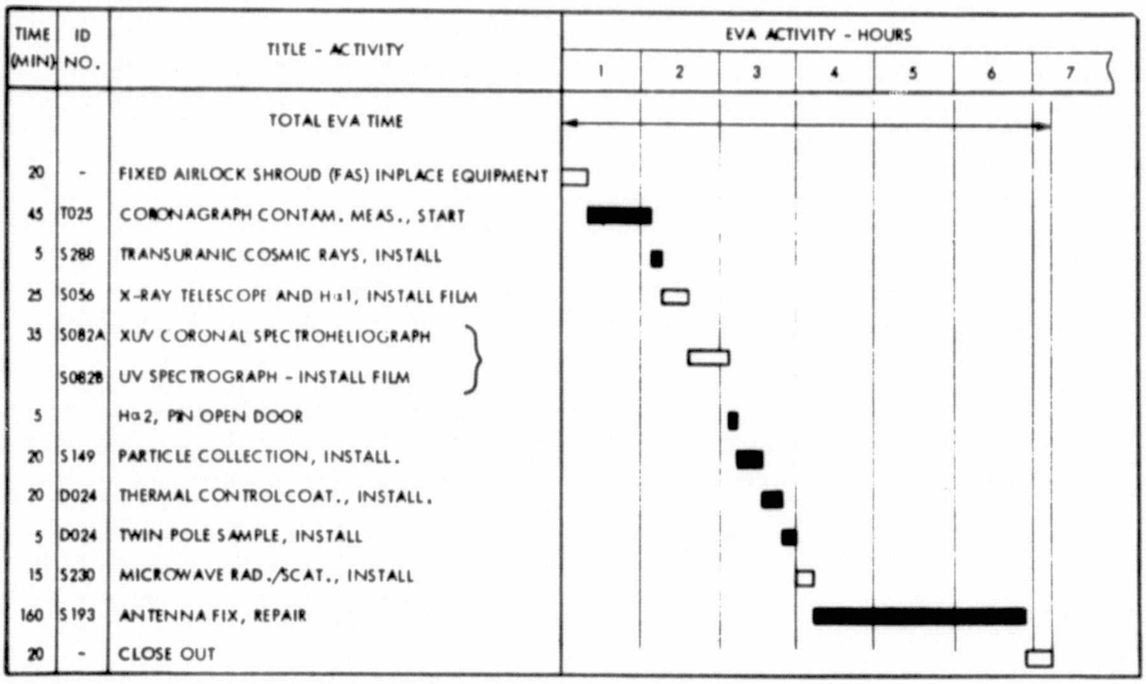
(1) SPAR Aerospace Products, Ltd., Ontario, Canada (re Model A-463).

(2) ASTRO Research Corporation, Santa Barbara, California.

(3) The Skylab Results Proceedings, Vol. 1 (AAS74-120, Skylab Extravehicular Activity by D. C. Shultz, JSC), 20th Annual AAS Meeting at USC, August 20-22, 1974.



REFERENCE: SKYLAB MISSION (SL-4, EVA-1, MD-7) FLIGHT PLAN

☐ ORIGINALLY SCHEDULED

■ NOT PLANNED BEFORE THE LAUNCH OF THE UNMANNED SKYLAB VEHICLE

AVERAGE INTEGRATED TASK TIME - 31 MIN.

Figure 2-24. Skylab EVA Task Times

2.4 ANALYSIS OF PAYLOAD OPERATIONS

The following data cover the study analyses which were performed in arriving at the EVA concepts detailed for each representative payload in the next section. The material covers routine operations, contingencies, and planned maintenance.

2.4.1 Routine Operations

One of the major analyses performed early in Task 3.0 was that of providing detailed payload function comparisons between automated modes and EVA modes of accomplishing representative payload operations. Table 1-8 shows the list of candidate EVA applications determined in the first phase of the study. After preliminary comparisons of automated and EVA applications were made for several representative payloads, it was noted that in the accomplishment of a given function (e.g., remove contamination shields), the comparisons were very similar.

It was decided, therefore, to provide a set of "basic activity sequence comparisons" which could be referenced as appropriate for each of the individual representative payload. In the individual payload comparisons, if any significant changes from the basic sequence are noted, these differences are included. The application of these concepts is described further in the representative payload analysis, Section III.

The basic activity sequences follow the same format as the Candidate EVA Applications matrix (Table 1-8). Each of the suggested applications in the matrix was considered for the basic activity sequence summary. Further analyses resulted in the elimination of several candidate functions, some across the board for certain type missions (e.g., 1.14 fill fluid systems for "delivery" missions). Others were eliminated as not appropriate for specific representative payload applications but were retained for the basic comparisons. In general, at this phase of the study, the activity comparison was completed for most of the suggested applications even though the practicality appeared marginal for the suggested EVA alternative.

Table 2-4 is the basic sequence listing comparing activity sequences for baseline and EVA serviced payloads. Generic comparisons are suggested in six of the seven applications groupings. The "Experiment Operations" section applied only to the Shuttle sortie representative payloads and the potential EVA operations in this area were of such a unique nature that a generic description of "basic" functions would not be meaningful. These experiment operations activities are discussed in detail in the representative payload operations description scenarios of the following section.

Referring to Table 2-4 summaries, it will be noted that the two left columns of the four-column format present the automated sequence of detailed operations togeter with the payload functional requirements for accomplishment of the particular step of the activity sequence. Similarly, the two right columns of the table summarize an EVA suggested sequence of accomplishing the given generic activity. The number preceding the activity title at the beginning of each group provides the reference to the Table 1-8 candidate EVA applications matrix. Specific hardware references are shown in parentheses following the activity heading.

2.4.2 Contingency Analysis

The value of EVA for resolving contingencies has been strongly recognized since Skylab. On that program, EVA can be credited with saving the entire mission, in terms of restoring thermal control and electrical power, but also with restoring a number of other functions/experiments as well. While it is a major purpose of this study to identify the benefits of designing for and operating with EVA on a routine basis, it was also desirable to quantify EVA savings in contingency situations.

2.4.2.1 Payload Model Contingencies

An overall analysis of the potential savings available in an EVA mode was initiated by review and categorization of historical data. The spacecraft historical anomaly data examined in this contract were related to Shuttle-delivered spacecraft and sortie missions. Most of the historical data were taken from Planning Research Corporation studies.(1) These study efforts included compiling, interpreting, and analyzing operational data for launches from 20 U.S. space programs. A total of 525 anomalies were examined.

All the subsequent analyses were based on these data. Typical anomalies were noted with actual consequences from which Shuttle payload analogs could be derived. A few examples are listed below which are credible not only from the PRC data, but in some cases from Skylab data:

1. Fluid system leakage
2. Partial deployment of contamination cover
3. Jamming of erection mechanism
4. Failure to separate cleanly
5. Failure of umbilicals to separate
6. No positive indication of a mechanism latch/unlatch
7. Failure of pyrotechnics to fire
8. Stem device failure
9. Loss or defocusing of TV cameras
10. Appendages failed to release or deploy
11. Loose wiring/connectors
12. Stuck valves/motor drives

It should be noted that the examples do not include component failures which do, however, contribute to the overall statistical analyses. Such failures are sometimes procedurally repairable (*a la* Skylab) but often require replacement parts. It should also be clear that substitution of manual techniques for deployment or extension mechanisms would preclude the failure described, thus would not contribute to contingency savings described in Section IV.

The evaluation of historical spacecraft failures yielded information for application to the Study Traffic Model for extrapolation purposes. The Study Traffic Model, described in detail in Section IV, was developed to encompass all payloads with potential EVA application which are defined as Shuttle payloads and are compatible with the "572 Flight Schedule". Using these extrapolations for the selected credible Shuttle payload failures should provide data with a reasonable accuracy, assuming equivalent state of the art, complexity, and level of reliability. While these factors were not considered, it was assumed that while Shuttle payloads might reflect improved state of the art, this factor might tend to be canceled out due to lower budgets with relaxed reliability. The PRC sample group encompassed 86 unique spacecraft flights based on 20 separate programs. Of this group only 7 flights were determined to be 100 percent successful, while 13 were considered total failures. The remaining 66 payloads had some 525 individual anomalies.

Since none of the study traffic model payloads have flown to date, it was necessary to use an extrapolation method to hypothesize the probable successes and failures and anomalies that might occur. From the traffic model developed for this study, 51 spacecraft and 23 sortie payloads were delineated, which resulted in 261 and 235 respective payload flights. Based on the extrapolation process, some 1593 automated and 1434 sortie anomalies are predictable. DoD and non-NASA sorties were added as shown in Table 2-5, which summarizes these extrapolations.

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(1) "Reliability Data From In-Flight Spacecraft; 1958-1970)", PCR-R-1453, dated November 30, 1971.

Table 2-5. Summary of Contingency Extrapolations

PRC SOURCE DATA:						
	PROGRAMS	PAYLOAD FLIGHTS	100% SUCCESS	100% LOST AT LAUNCH	OTHER PL'S WITH ANOMALIES	NUMBER OF ANOMALIES
SAMPLE GROUP	20	86	7	13	66	525
SHUTTLE PAYLOAD DATA:						
NASA AUTOMATED	51	261	21	39	200	1593
NASA SORTIE	23	235	19	35	180	1434
DOD AUTOMATED	N/A	155	13	23	127	946
NON-NASA SORTIE	N/A	43	3	6	33	262
STUDY TRAFFIC MODEL			EXTRAPOLATED FROM PRC TOTALS			

2.4.2.2 Analysis of Time-Critical Contingencies

A further analysis of the historical payload failure data was performed to identify failures whose consequence could be time-critical in terms of mission success or equipment losses. Failures in various subsystems were found to have time-critical results frequently in one or more categories. Time-critical categories are defined to include the following:

1. *Loss of consumables.* Leakage of spacecraft fluid supply causing mission abort and subsequent reflight if not halted.

2. *Loss of specimen.* Thermal and atmospheric environment failures time critically affecting bio-specimens.

3. *Missed launch window.* Sun-synchronous and geosynchronous spacecraft sensitive to the timing of their separation from Shuttle.

4. *Missed ground track or target.* Opportunities on a sortie mission limited due to look angles, field of view of changing pheonomena.

5. *Off-nominal thermal condition.* Trends in paylcad thermal condition due to failures causing serious secondary effects.

Table 2-6. Matrix of Time-Critical Consequences

AFFECTED SYSTEMS	PROBLEMS	TIME CRITICAL CONSEQUENCES				
		LOSS OF CONSUM	LOSS OF SPECIMEN	LAUNCH WINDOW	GND/TRK TARGET	THERMAL CONDITION
FLUID SYSTEMS	FLUIDS LOSS	√	√	√	√	√
STRUCTURES & MECHANICS	KINEMATICS FAILURE	—	√	√	√	√
ELECTRICAL SYSTEM	OFF-NOMINAL	√	√	√	√	√
CONTROLS & DISPLAYS	FAILED INDICATORS/ CONTROL	—	—	√	√	—
INTERFACES	DEPLOYMENT, ENGAGEMENT/ DISENGAGEMENT	—	√	√	√	√

Loss of consumables due to leakage of payload propellants, cryogenics, pressurization or special experiment gases on a continuing basis will terminate a mission. Mechanical elements, including deployment devices, protective shield latches and antennas, have various failure modes requiring quick reaction to prevent one of the time-critical consequences. Similar impact can occur with failures in electrical power, control circuits and with failed interfaces. The above contingencies are listed in Table 2-6, including the affected systems and the time-critical consequences. A discussion of each category follows.

Loss of Consumables

A typical example of a time-critical contingency is the loss of consumables such as gaseous nitrogen, which may be used as a pressurizing agent or as a propellant in cold gas systems, Figure 2-25. Assuming a given volume, temperature and isothermal expansion, the length of time for pressure to drop to a critical level was determined as a function of hole size. This point can be avoided if a successful repair can be effected. The rate at which the pressure drop occurs will determine the time available to prepare for EVA and perform a fix. Ability to locate the hole and perform a repair depends upon the reaction capability of the astronaut and the EVA equipment provided by the STS.

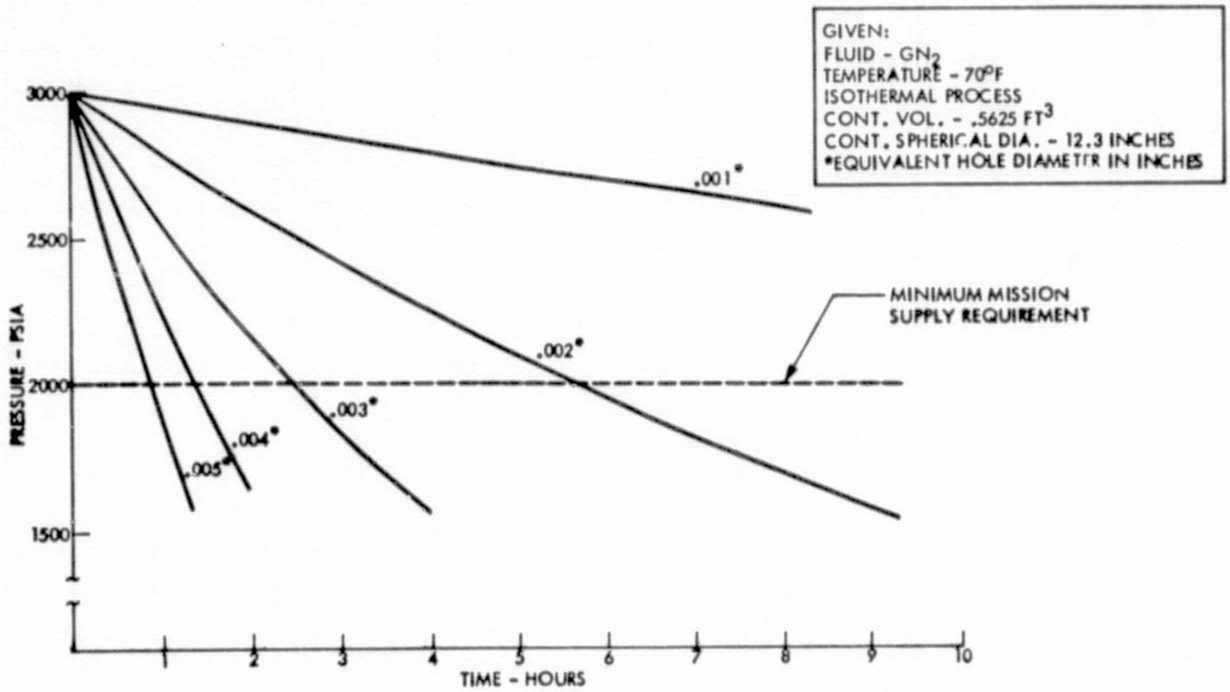


Figure 2-25. Typical Gas Leak Rates

Loss of Biological Speciman

Typical time histories for various equivalent hole sizes will cause a loss of *cabin* atmosphere, resulting in a critical life support level within hours. Precise results are dependent upon the variables defined for this specific case; however, the trend is common to all such cases. Wherever a payload includes biospecimens, their loss could only be prevented by prompt reaction to prevent further decay of life support. See Figure 2-26.

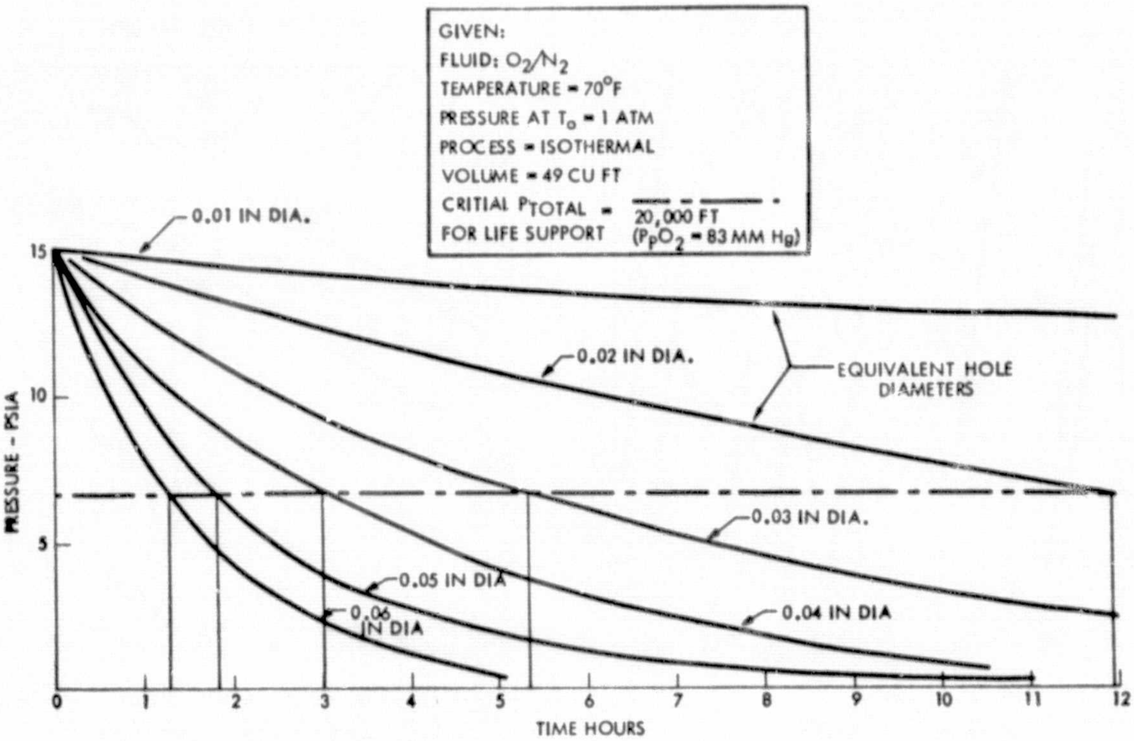


Figure 2-26. Loss of Life Support Atmosphere

Missed Launch Window

Sun-synchronous and geosynchronous spacecraft are sensitive to the timing of their separation from Shuttle so as to ensure proper spacecraft and stage pointing and stabilization and to initiate transfer orbit injection (TOI) with minimum energy expenditure. Missed opportunities due to contingencies will require either increased prerformance margins, extended wait times, or both. Illustrated in Figure 2-27 are orbit paths and typical wait periods for the next opportunity assuming no significant propellant margins for phase or plane changes. Typically, when sun-synchronous orbit spacecraft such as the EOS are not injected into transfer orbit as planned, a wait of 27 orbits would be required before TOI to the same orbital trace at the same sun angle. The injection must occur on an ascending node at a whole orbit period such that twice the transfer orbit period (P_T) plus the number of Shuttle orbits (N) times the Shuttle orbit period (P_s) equals the number of Shuttle orbits (minus 1) times the planned operational period (P_o) [e.g., $2P_T + N - P_s = (N-1)\ P_o$]

With the Shuttle at 300 n mi for the example shown for the EOS, then $1.6585 + 27 \times 1.596 \cong 26 \times 1.722 \cong 45$ hours or 27 orbits, although options are open earlier for different placement.

Placement of geosynchronous spacecraft subsequent to a missed opportunity would require a minimum energy wait time of 24 hours. Options would include acceptance of a different orbital position, additional spacecraft phasing, or placing the spacecraft into a (holding) elliptical orbit for two orbits. Release time or TOI for low earth orbit, planetary or other high energy orbits is not a significant constraint.

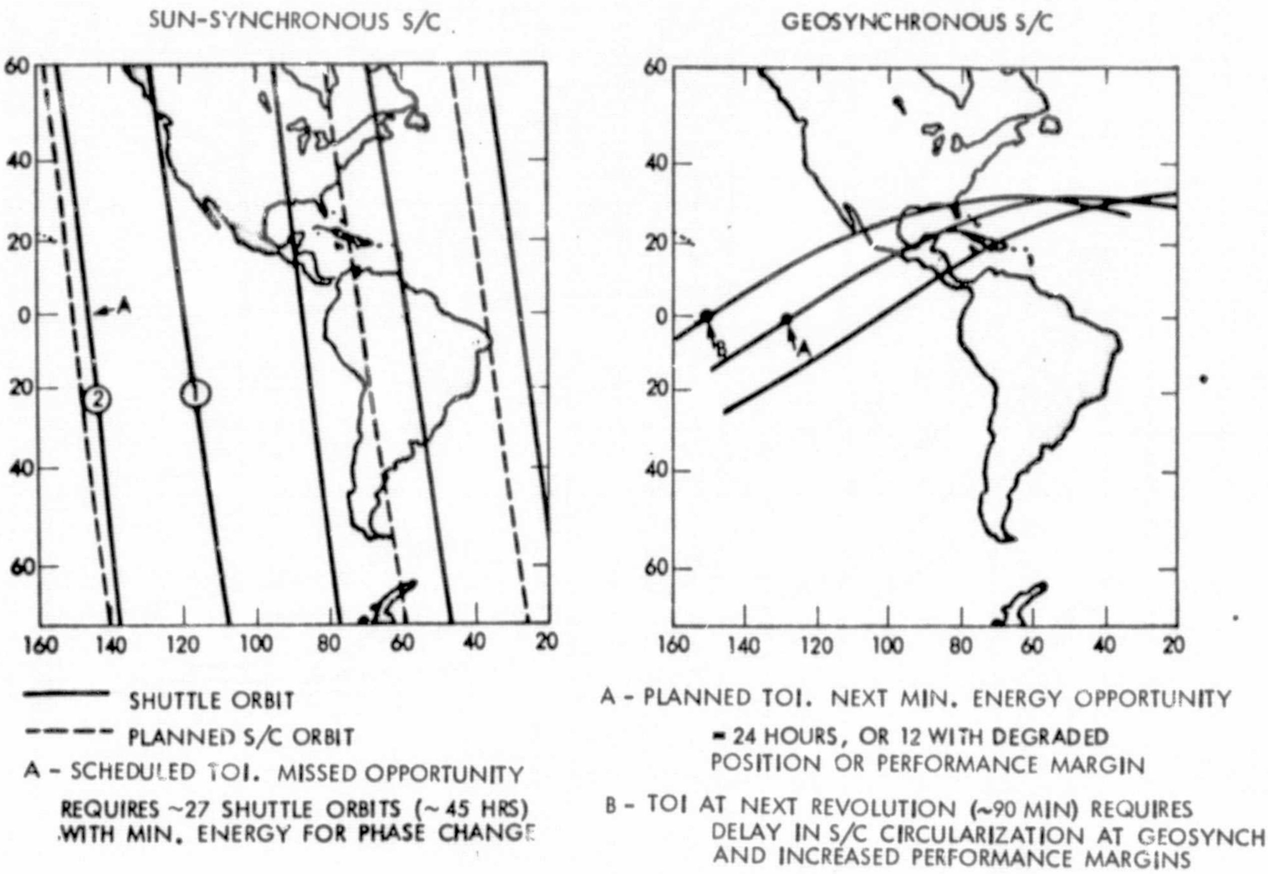


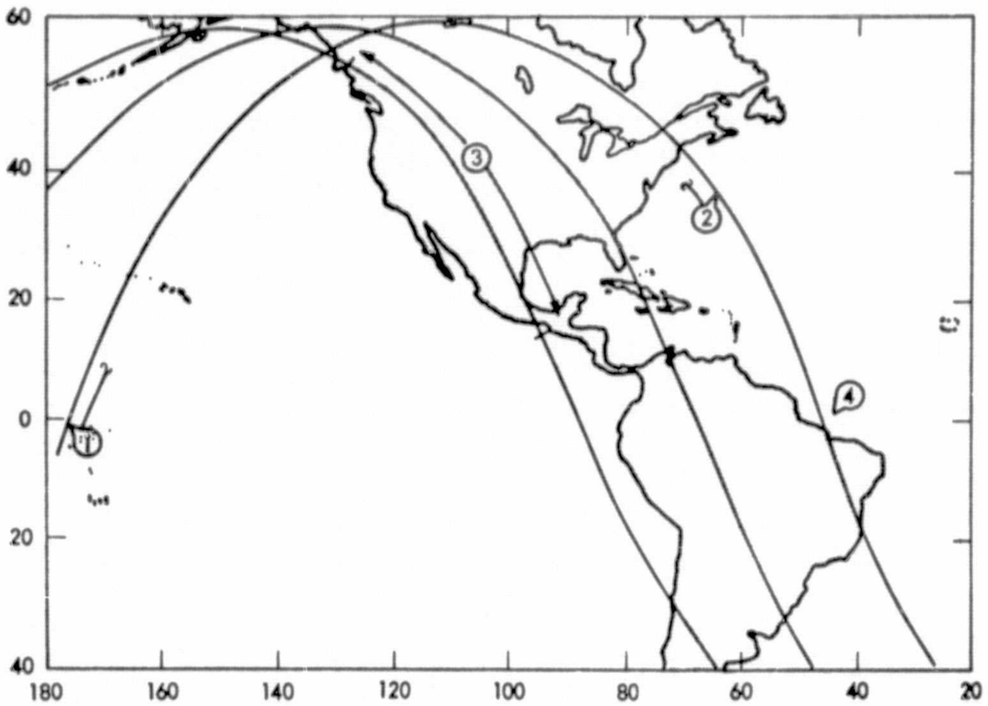
Figure 2-27. Missed Launch Window

Loss of Ground Track or Target on Sortie Missions

Target opportunities on a sortie mission are limited due to look angles, fields of view or changing phenomena. Certain payloads have planned events, such as the AAL Barium Cloud Release experiment. This may be performed with a ground launch which requires that the on-board sensors be ready on a one-orbit opportunity. Higher resolution sensors cover narrow bandwidths of ground track and may be sensitive to loss of one pass due to a contingency failure. Even where a mapping pass is repeated, planned mission activities may be impacted if repeat mapping runs are required. These typical situations for sortie payloads are shown in Figure 2-28. Automated spacecraft will acquire ground targets; however, they are not time-critical in respect to contingency anomalies occurring before release from the Shuttle.

Off-Nominal Thermal Condition

Another time-critical situation which can potentially terminate a mission is an off-nominal thermal condition. Thermal degradation from various causes such as loss of cryo coolants, mechanical failures in passive systems, valve or plumbing obstruction in coldplates or radiators in active systems, etc., can potentially affect virtually every spacecraft and sortie payload. Many of these failures could be repaired by EVA, and may be time-critical within the limits shown in Figure 2-29.



TYPICAL SITUATIONS FOR A 60-DEG INCLINED ORBIT
①——② BARIUM CLOUD EXPMT--CLOUD WILL MOST LIKELY DISAPPEAR PRIOR TO NEXT ORBIT.
① INITIATE BARIUM LAUNCH. ② OBSERVATION OF BARIUM CLOUD.
③ MAPPING PASS--WILL NOT BE DUPLICATED WITH REQUIRED OVERLAP BEFORE NEXT DAY.
④ MISSED TARGET--MAY BE RANDOM EVENT (TARGET OF OPPORTUNITY OR SENSOR FOV TOO NARROW TO OBSERVE ON SUBSEQUENT PASS.

Figure 2-28. Loss of Ground Track or Target

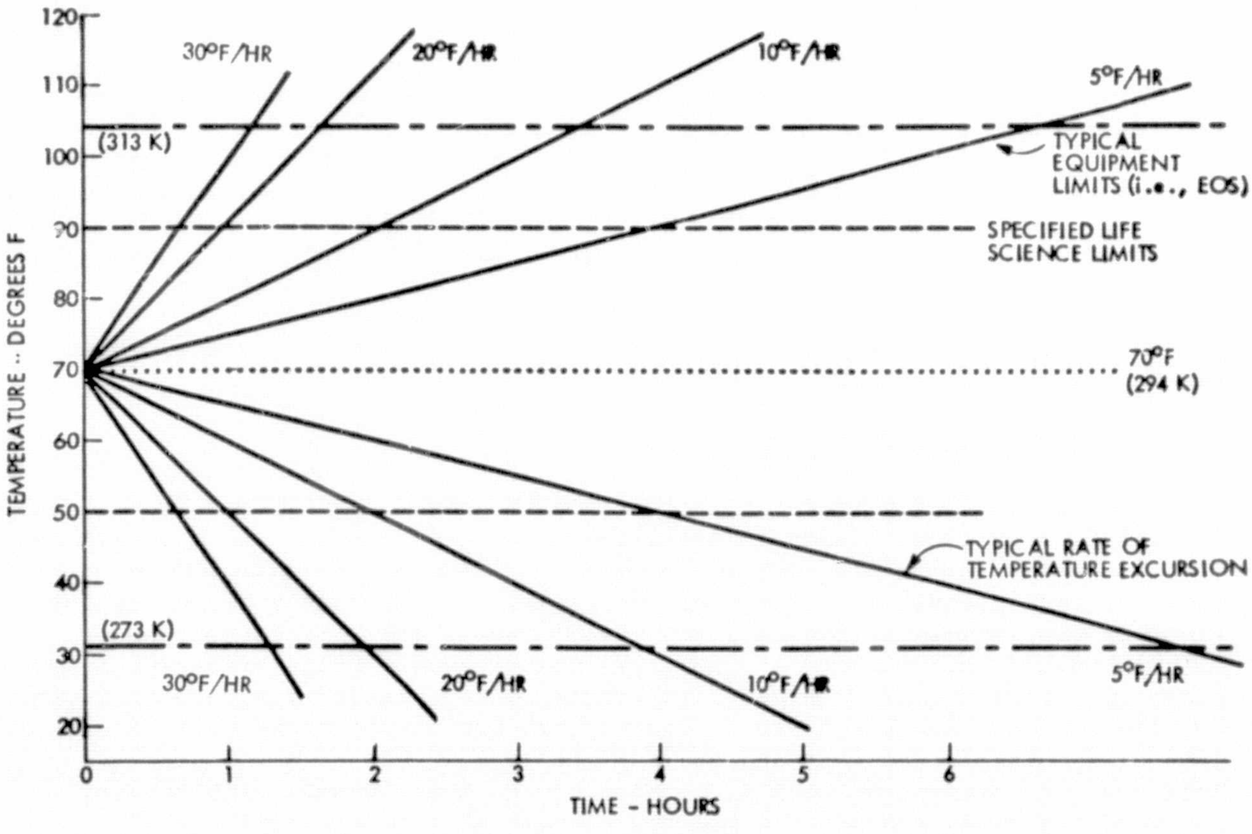


Figure 2-29. Typical Temperature Excursion Rates

For illustrative purposes, 70 F was selected as nominal with a 20-degree excursion either side bounding the allowable limits. This could well be a biomedical experiment and any temperature deviation beyond the limits causes the loss of the experiment. Additional levels above or below nominal temperature may, if allowed to continue, cause irreversible damage to experiment or spacecraft equipment.

Various realistic temperature excursion rates were assumed. Within the allowable time to repair, one can postulate the ability to perform an EVA to correct the thermal condition.

Summary

Based on the number of anomalies in the PRC data which resulted in time-critical consequences, percentages of total payload deliveries were calculated to apply to Shuttle payloads. An initial screening of the Shuttle payloads was made so that the percentage would only be applied to those payloads with a potential for the defined time-critical consequence. For example, only payloads with biospecimens could have a potential loss of specimens. Further screening eliminated, where feasible, those anomalies where EVA response was precluded. For example, automated spacecraft "missed targets" will only occur during autonomous operations. Other categories must be considered on the basis of occurring anytime during a mission. Thus, for the automated spacecraft which might suffer loss of consumables, only a small percentage may occur during the delivery phase where EVA response is possible. The sum of all time-critical anomalies is about 15 percent of the total extrapolated number of potential anomalies. The results are listed in Table 2-7. The numbers on the row labeled PRC Data are based on examination of the historical source. Thus, 26 percent of the spacecraft were determined to have suffered loss of consumables due to anomalies. Since 255 automated spacecraft and 230 sortie payloads in the traffic model require fluid consumables, it was predicted that 26 percent (or 122 total) of the traffic model payloads would exhibit the same failure. These numbers are entered on the line labeled "NASA" under the heading "Equivalent Payload". DoD and Non-NASA Sortie Equivalent Payloads were calculated on the basis of the number of flights only since payload details were not available.

The cost savings analysis attributed to contingencies is discussed in Section IV of this report.

2.4.3 Planned Maintenance Analysis

The analysis of planned maintenance in the study was limited to comparing automated on-orbit maintenance to equivalent maintenance performed by EVA. The evaluation was essentially programmatic in that it compared equipment and transportation cost differences. The analysis was enhanced by the study of two representative payloads which have baselined alternate modes: EOS, automated maintenance; and LST, EVA maintenance. Costs of design differences in payloads were determined to require more detailed analysis than were available in the study. Costs of spares were considered to be more of a function of maintenance concept and sparing philosophy than of maintenance mode. There may be some spares cost difference due to EVA/automated influences; however, the study ground rule elected to omit this consideration.

Table 2-7. Potential Payload Time-Critical Anomalies

TYPE OF DATA	LOSS OF CONSUM-ABLES	LOSS OF SPECIMENS	MISSED LAUNCH WINDOW	MISSED TARGET	THERMAL ANOMALY	TOTAL BASE
PRC DATA						
NO. ANOMALIES	22	8	75	144	27	525
RATE/86 PL'S	0.26	0.09	0.87	1.67	0.31	6.1
SHUTTLE DATA						
NO. POSSIBLE PAYLOADS						
NASA AUTO S/C	255	24	152	-	255	261
NASA SORTIE	230	39	-	36	181	235
TOTAL	485	63	152	36	436	496
EQUIV PAYLOAD						
NASA	122	6	132	60	135	3026
DOD	39	0	78	-	47	-
NON-NASA SORTIE	10	1	-	6	9	-

There are several mission options for performing maintenance on both low earth orbit (LEO) and high earth orbit (HEO) spacecraft. For the present study, low earth orbit spacecraft are those which are operating at altitudes and inclinations which allow the Shuttle orbiter to rendezvous directly with the reusable spacecraft. (Spacecraft with integral propulsion packages, such as EOS, are included in this category.) This provides the simplest comparison of automated servicing system to the EVA-augmented system for performing the spacecraft on-orbit maintenance functions.

For the high earth orbit spacecraft, two additional alternatives were considered. The first involved using an upper stage system such as the Tug for delivering either the automated servicing unit or a manned servicing module to the operating orbit of the spacecraft being maintained. The other approach was to use the upper stage to retrieve the operational spacecraft and bring it down to the Shuttle orbit. The spacecraft maintenance would then be performed while attached to the Shuttle, either with an automated or with an EVA approach.

The significant difference between LEO and HEO maintenance missions lies in the added costs of the upper stages and operations. The center section of Figure 2-30 illustrates that one Shuttle-Tug launch would be required to carry an automated servicing module to the geosynchronous orbit. Previous studies have shown that two high technology Tugs would be required to transport a manned servicing module from the Shuttle altitude to the geosynchronous altitude and return. Because of the size and mass of the required Tugs, this maintenance would require two Shuttle launches.

The bottom diagram of the figure illustrates mission requirements for servicing the HEO spacecraft at the Shuttle orbit. Two Tugs and two Shuttles are also required for this mission mode.

A cost comparison of the alternate maintenance concepts is presented in Section IV.

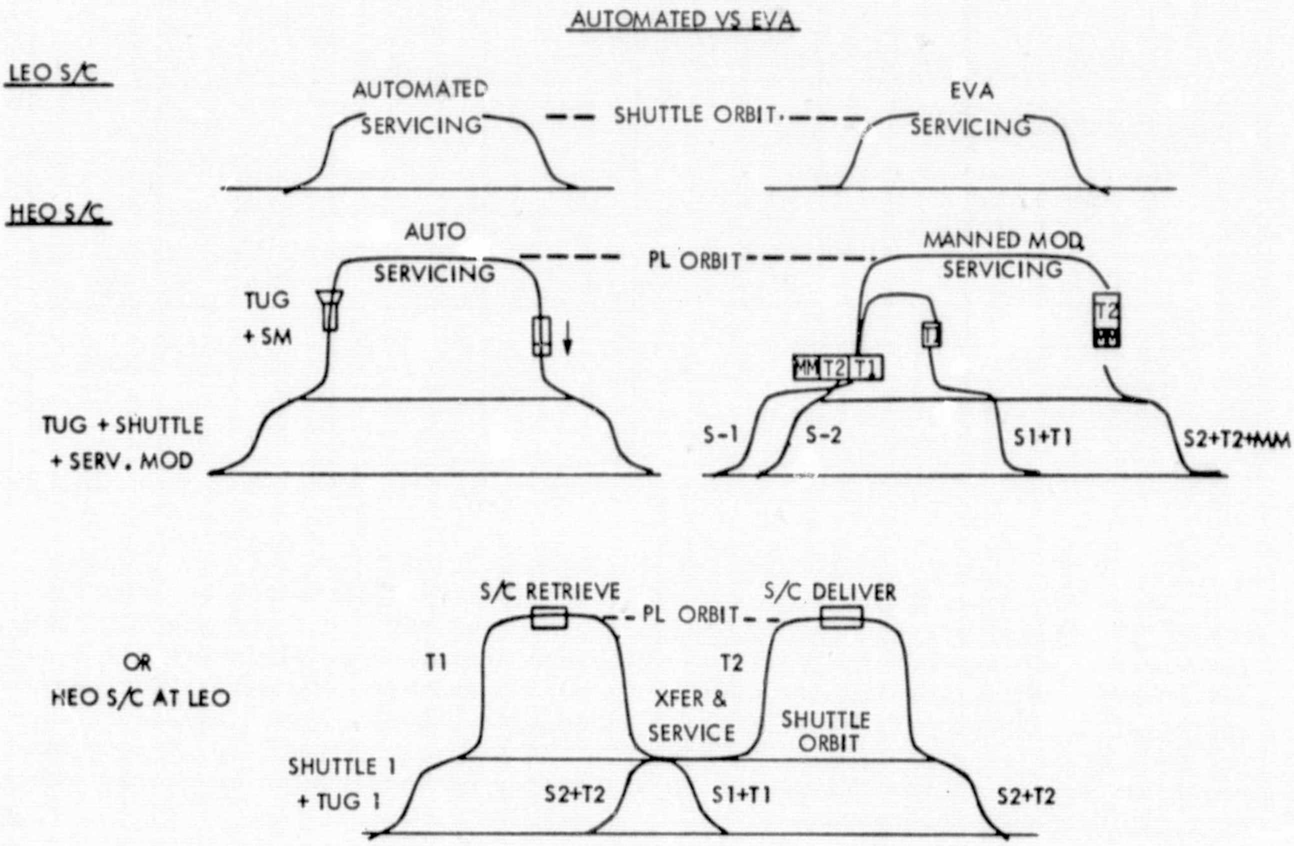


Figure 2-30. Maintenance Mission Options

It should be noted that none of the representative payload source data provided the level of detail indicated in the basic activity sequence comparisons. Each of the activity areas could have other approaches for accomplishment and a more detailed study could be effectively utilized in order to select more optimum approaches in both the automated and the EVA modes. The given sequence comparisons do illustrate the basic differences of the automated and the EVA-oriented approaches. The basic sequences as amplified by variations for each payload were used in estimating timelines for each representative payload (Section III) and in determining program cost comparisons (Section IV).

TABLE 2-4.

BASIC SEQUENCE LISTING

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
1. PRE-OPERATIONS			
1.1 REMOVE CONTAMINATION SHIELDS (Optical Surfaces, Sensors, Etc.)			
Activate power circuits for contamination shield removal	PSS control console	Proceed to work platform	Handholds, work platform, foot restraints
Provide visual display of contamination shields	CCTV	Remove shields from sensors	Manually removable shields
Operate shield unlatch mechanism	Electric operated latch	Store shields in pallet area	Storage facility
Operate shield opening mechanism	Automated shield removal mechanism	Visual inspection of sensors	Verbal communication
Operate shield lock for stored position	Automated latch mechanism		
Monitor above operations	PSS, CRT display		
Power down circuits	PSS control console		
1.2 DISENGAGE APPENDAGE BOOST LOCKS (Solar Panel, Antenna, Etc.)			
Activate power circuits for boost lock system	PSS control console	Proceed to work platform	Work platform, foot restraints, handholds
Provide visual display of boost lock attach points	CCTV	Unlock boost latches for panels, antennas, etc.	Manual latches
Perform boost lock unlatch operations in sequence	Electromechanical latches	Verify all clear for extendibles erection	On-site inspection, verbal communication
Verify boost latches clear for extendible deploy operations	Event sensing microswitches and display		
Power down circuits	PSS control console		
1.3.1 ERECT ANTENNA (Communications, Radar)			
Verify all clear	CCTV in payload bay	Proceed to work station	Work platform, handholds, foot restraints
Activate power circuit for panel erect mechanism	PSS control console	Verify all clear	On-site inspection
Operate antenna deployment system	Electric gearmotor mechanism	Rotate antenna to operating position	Manual operating antenna rotation mechanism
Verify completion of deployment	Event sensing microswitch, CCTV	Latch antenna in operating position	Manually operated latch
Power down circuits	PSS control console	Verify completion of deployment	On-site inspection
1.3.2 ERECT SOLAR ARRAYS (Solar Panel)			
Verify all clear	CCTV in payload bay	Proceed to work platform for solar array deployment	Work platform, foot restraints
Activate power circuits for solar array deployment motors	PSS control console	Verify all clear, remove solar panel socket cover	Manually released cover

BASIC SEQUENCE LISTING

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
Operate solar panel deployment motor	Electric gearmotor	Remove solar panel from storage, insert in spacecraft solar panel socket	Manually handled components
Verify completion of stem rotations to operating positions	TV display, event sensing microswitches	Lock solar panel stem in position	Manual locking device
Shut down power for deployment motor	PSS control console	Verify electrical circuit integrity	Test from PSS control console
1.3.4 ERECT INSTRUMENT BOOM/MECHANISM (Magnetometer Boom, Bi-stem Astromast, Pole Assembly, etc.)			
Inspect instrument boom and mechanism for flight damage		Proceed to work area	Work platform, foot restraints
Verify data circuit operational	PSS checkout	Unlatch flight restraints	Hand operated latch mechanisms
Extend unit to operational position	PSS control console	Verify all clear for boom erection	
		Remove boom socket cover	Manually released cover
		Erect instrument boom on spacecraft	Manual operation, motor drive assist as required
		Lock boom in position	Locking device attached to boom
		Verify data circuit integrity	Test from PSS control console
1.7 INSTALL INSTRUMENTS (e.g., Vector Magnetometer, scalar magnetometer)			
(Instruments already installed in automated mode)			
Inspect instruments for flight damage	CCTV in payload bay	Transport instruments from flight cabin storage to instrument boom storage on pallet	Handholds, tether, foot restraints on pallet
Verify data circuit integrity	PSS checkout system	Remove instrument socket covers from instrument boom	Spring loaded swing covers
		Install instruments on boom	Manual operation
		Verify installation and lock-in position	Visual inspection, pin locks attached to instruments
1.8 TEST/CHECKOUT (Instrumentation and Subsystems)			
Activate checkout console and electronics	PSS control console	Activate checkout console and electronics	PSS control console
Provide visual display of mechanically activated components	CCTV in payload bay	Test power and electronic circuits	PSS checkout console
Test power and electronic circuits	PSS checkout console	Proceed to viewing location to observe mechanical operations	Handholds, tether (Illumination, on-site observation, PSS checkout console)
Test solar panel operation	PSS checkout console, CCTV	Test solar array operation	PSS checkout console

BASIC SEQUENCE LISTING

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
Check experiment sensor operation	PSS checkout console	Check spacecraft sensor operation	PSS checkout console
Check spacecraft subsystems	PSS checkout console	Check spacecraft subsystems	PSS checkout console
Shut down test and checkout operations	PSS control console	Shut down test and checkout operations	PSS control console, EVA astronaut proceed to next sequence location
1.10 VISUAL INSPECTION (Pre-Release or Pre-Operations Inspection)			
Activate visual inspection system for pre-release inspection	PSS control console, TV camera and light source on RMS or equivalent	Proceed to spacecraft location	EVA work platforms, handholds
Inspect payload attach fitting	PSS control console	Inspect payload attach fitting	On-site visual inspection, verbal reports to PSS
Inspect retention devices, interfaces, exterior surfaces, etc.	PSS control console	Inspect retention devices, interfaces, exterior surfaces, etc.	On-site visual inspection
Inspect extendible devices	PSS control console	Inspect extendible devices	On-site visual inspection
Inspect external instrumentation	PSS control console		
Power down visual inspection system	PSS control console		
1.11 REMOVE PYRO SHORTING PLUGS (Propulsion Module, Pyro Disconnects)			
Activate shorting plug release circuit	PSS control console	Proceed to shorting plug location	Handholds, etc.
Provide visual display of shorting plug release mechanism	CCTV	Remove shorting plug, store on orbiter pallet	Shorting plug with manual handle, spring for storage
Operate shorting plug release mechanism	Electromechanical retraction mechanism	Verify pyro circuit integrity	PSS checkout console
Verify pyro circuit integrity	PSS checkout console		
Power down release circuit	PSS control console		
1.13 POWER DEADFACE AND SWITCHOVER (Spacecraft)			
Activate power switchover device circuit	PSS control console	Proceed to spacecraft switchover device	Handholds, tether
Operate switchover mechanism	Electromechanical switch retraction mechanism	Operate switchover device	Manual operating switch-over mechanism
Verify switchover	Event sensing microswitch and display	Verify and lock device in open position	Manual lock device, on-site inspection, light source
Power down switchover circuits	PSS control console		
1.14 FILL FLUID SYSTEMS (Nitrogen Gas for Attitude Control, Servicing Missions, Experiment Gases, Etc.)			
(System loaded prior to launch)			

BASIC SEQUENCE LISTING

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
Activate fluid container display circuit	PSS control console	Proceed to spacecraft fluid fill fitting	Handholds
Verify status of fluid supply	PSS checkout console	Remove fluid fill fitting cover	Work platform, restraints
Monitor test of attitude control jets, etc.	PSS checkout console	Fasten fluid supply hose to fluid fill fitting	Manual operation
		Turn on supply valve on storage tank	Lever wrench
		Monitor fill operation, shut off supply tank valve	PSS checkout console, lever wrench
		Remove gas supply hose and return to storage position	Manual operation
		Verify status of fluid supply	PSS operation, visual inspection, tank gauges

3. CONTINGENCY OPERATIONS

3.1 RELEASE/OPERATE JAMMED MECHANISMS (Solar Panel, Antenna Mechanisms, Experiment Booms, Etc.)

Provide visual display of mechanism operating components	CCTV	Proceed to area of malfunction	EVA handholds, etc.
Identify mechanism lockup, if external attempt operation	CCTV	Inspect for mechanism jammed source	Visual inspection
Grasp component part & move to release if possible	RMS	Manually release jammed part if feasible	EVA hand tools
If internal restraint, remove component and reinstall	RMS, special end effector	Procure proper tools and release mechanism	Special tools in EVA storage compartment
Test for operation	PSS control console		
If not cleared, jettison			
Power down affected circuits	RMS control station, PSS control console		

3.2 JETTISON RETRACT/STOW FAILED EXTENDIBLES (Solar Array, Booms, Etc.)

Activate RMS	RMS control station	Proceed to payload location	EVA handholds
Grasp mechanism and fold down to stored position	RMS, CCTV	Manually remove or stow mechanism. Lock for entry	Manual operation, hand operated entry latches
If retraction not feasible, fire pyros and jettison unit	Pyros, RMS		
Deactivate affected circuits	RMS control station, PSS control console		

BASIC SEQUENCE LISTING

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
3.3 ENABLE/DISABLE SIGNAL POWER PATHS (Malfunctioning Circuits)			
Checkout circuits via PSS checkout console		Checkout circuits	PSS checkout console
Select alternate circuit routing as available	Wiring panel in orbiter cabin	Select alternate circuit	Orbiter cabin wiring panel or wiring panel at subsystem end. Hand tools, hand held voltmeters, jumper cables, etc.
Checkout re-routed circuits			
		Checkout re-routed circuits	PSS checkout console
3.4 PHOTO/TV COVERAGE (Malfunctioning Mechanisms)			
Activate RMS and attached TV	RMS control station	Proceed to area of malfunction	Handholds, tethers, etc.
Photograph malfunctioning mechanisms from several angles	CCTV in payload bay and on RMS, image recorder in PSS	Photograph malfunctioning mechanisms from several angles	Hand held film camera, hand held CCTV
3.5 EQUIPMENT DISASSEMBLY (Malfunctioning Components)			
Activate RMS	RMS control station	Proceed to area of malfunction	Handholds, tethers, etc.
Provide visual display of malfunctioning component	CCTV in payload bay and on RMS	Disassemble, cut, store equipment component	Hand tools, storage locker, hand activated clamp for storage security
Monitor mechanical disassembly, cutting, storing activities	PSS control console display		
Disassemble, cut, store	RMS and special end effectors, storage compartment, adjustable storage latches and drive mechanisms		
3.6 MECHANISM REPAIR (Malfunctioning Components)			
Move component to airlock	RMS	Repair malfunction component in position or	EVA hand tools
Transfer component to PSS	Airlock	Move disassembled component to work bench	Handholds, etc.
Repair component	Cabin tools, spares	Repair mechanism	EVA hand tools, spares
Transfer component back to installation area	Airlock, RMS	Transfer component back to installation area	Handholds, etc.
3.7 TROUBLESHOOTING (Malfunctioning Subsystems)			
Provide visual display	CCTV in payload bay and on RMS, light source	Examine subsystem visually	Portable light
Run circuit continuity checks	PSS checkout console	Make electrical circuit continuity checks	Hand test equipment
3.8 MODIFICATION (Malfunctioning Mechanisms)			
Similar to 3.6 (Mechanism Repair) except no spares available		Similar to 3.6 (Mechanism Repair) except no spares available	

BASIC SEQUENCE LISTING

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
4. SEPARATE SPACECRAFT			
4.1 REMOVE UMBILICALS (Orbiter to Spacecraft)			
Activate umbilical retraction mechanism circuit	PSS control console	Proceed to umbilical location	Handholds, work platform
Provide visual display of operation	CCTV	Remove umbilicals from spacecrafts	Manual operating umbilical connection
Operate umbilical disconnect mechanism	Electromechanical linear mechanism	Lock umbilical in stored position	Manual operating device to lock umbilical to orbiter or docking platform
Verify umbilical locked in storage position	Event sensing microswitch, and display		
Power down umbilical circuit	PSS control console		
4.2 DISENGAGE SPACECRAFT			
Activate RMS	RMS control console	Proceed to position for observing spacecraft deployment	Handholds, tethers
Move spacecraft from docking platform to extended RMS position	RMS control console (RMS attached to spacecraft in previous operation 1.4)	Observe automated RMS sequence	Verbal comments to PSS
Align spacecraft to correct orientation	RMS control console		
Release RMS end effector attachment, impart separation velocity	RMS control console		
Return RMS to stowed position	RMS control console		
Power down RMS	RMS control console		
4.3 TRANSFER TO SPACECRAFT GROUND			
Activate ground transfer mechanism circuit	PSS control console	Proceed to ground transfer mechanism location	Handholds, etc.
Operate ground transfer mechanism	Electromechanical umbilical disconnect	Operate ground transfer mechanism	Manual operating umbilical disconnect and lock
Verify transfer complete	Event sensing microswitch and display	Verify transfer complete	On-site inspection
Power down circuits	PSS control console		

BASIC SEQUENCE LISTING

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
	5. DOCKING OPERATIONS		
5.1 RELEASE BOOST LOCKS			
Activate RMS circuits and docking circuits	RMS control station	Proceed to work station	Handholds, tethers
Operate boost lock release mechanism	PSS control station electro-mechanical latch mechanisms	Release boost locks	Manual operating latch release
Verify mechanism release	Event sensing microswitches, PSS display		
5.2 COCK BERTHING MECHANISM			
Check operability of spacecraft capture latches	PSS control console	Proceed to work station	Handholds, work platform
		Inspect capture latches	On-site inspection light source
5.3 DIRECT PLACEMENT			
Provide visual display of spacecraft retrieval and placement operations	CCTV	Proceed to position to observe spacecraft retrieval and placement	Handholds, tethers
Orient Shuttle to docking position	PSS control console	Observe and verbally direct movement of spacecraft from capture location to docking position	Communication with PSS and RMS control
Operate RMS to retrieve spacecraft and transfer to docking latching position	RMS control console	Move to payload bay position to manually assist final docking operations	Handholds, work platform
Verify spacecraft proper alignment for latching	TV monitor, light source		
5.4 ENGAGE DOCKING LATCHES			
Activate docking latch circuits	PSS control console	Manually operate docking latches in sequence	Manual operating latching mechanisms
Provide visual display of latching operations	CCTV	Verify latch lock integrity	On-site inspection, light source
Operate docking latch mechanisms in sequence	Electromechanical latch mechanisms		
Verify attachment	Event sensing microswitches		
Power down circuits	PSS control console		
5.5 CONNECT UMBILICALS (PAYLOAD TO ORBITER)			
Activate umbilical operating circuits	PSS control console	Proceed to umbilical storage location	Handholds, tethers
Unlatch umbilical storage position lock	Electromechanical latch	Unlock umbilical retention device	Manual operating lock
Provide visual display of umbilical transfer	CCTV	Connect umbilical to payload	Manual transfer

BASIC SEQUENCE LISTING

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
Operate umbilical transfer mechanism	Electromechanical transfer mechanism	Verify umbilical circuit integrity	On-site inspection, PSS checkout console
Verify umbilical circuit integrity	Event sensing microswitches, PSS checkout console		
Power down transfer circuits	PSS control console		
5.6 CONNECT TO SHUTTLE POWER			
Activate transfer mechanism circuits	PSS control console	Proceed to ground transfer location	Handholds, etc.
Provide visual display of operation	CCTV	Operate ground transfer mechanism	Manual operating transfer mechanism
Operate ground transfer umbilical	Electromechanical transfer mechanism	Verify transfer complete	On-site inspection
Verify transfer complete	Event sensing microswitches		
Power down circuits	PSS control console		
7. PREPARE FOR RETURN			
7.1 INSTALL/CLOSE CONTAMINATION SHIELDS (Earth sensors, sun sensors, star sensors)			
Activate circuits for contamination shield system	PSS control console	Proceed to MFM work platform	EVA work platform, handholds, foot restraints
Provide visual display of contamination shields	CCTV in payload bay	Remove shields from storage	Manual operation
Operate "shield open" latch mechanisms to release	Electric screw actuated latch	Install shields on sensor openings	Snap-on shields with spring latch
Operate "rotate shield" mechanism to close shields	Electric screw driven mechanism	Visual check for installation completion	Intercomm system, EVA to PSS
Operate shield lock latches to secure in closed position	Electric screw actuated latch		
Monitor above operations	PSS CRT display		
Shut down power circuits	PSS control console		
7.2 ENGAGE ENTRY LATCHES (Solar panel, antenna dish, etc.)			
Activate circuits for entry latch system	PSS control console	Proceed to work platform for entry latch secure	Work platforms, foot restraints, etc.
Provide visual display of entry latch attach points	CCTV in payload bay	Manually lock entry latches	Hand lever operated mechanisms
Operate entry latch attach mechanisms in sequence	Electric screw operated latches (2)		
Verify payload mechanism secured	Event sensing microswitches and display		
Shut down power	PSS control console		

BASIC SEQUENCE LISTING

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
7.3.1 STOW ANTENNA			
Entry latches covered in 7.2, no further activity required		Entry latch activities covered in step 7.2	
7.3.2 REMOVE/STOW/RETRACT SOLAR ARRAY			
Activate power circuit for antenna stow mechanism	PSS control console	Proceed to work platform	Hand holds, tethers, foot restraints
Operate antenna stem fold mechanism	Gear motor drive mechanism	Remove solar array	Manual operation
Verify completion of stem rotation	Event sensing microswitches, display	Store solar array in pallet compartment	Storage compartments
7.3.3 REMOVE/STOW/INSTRUMENT BOOMS/SUNSHADE			
		Proceed to work platform	Handholds, tethers, foot restraints
Retract sunshade and stow	PSS control console, sunshield, deployment arm	Manually retract/stow sunshield	Sunshield, deployment arm, hand tools
		Latch sunshade	Over-center latches
7.7 STOW/LOCK REMOVED COMPONENTS (Solar array, boom, etc.)			
None		Check proper positioning of removed components in storage compartment	EVA visual operation, light source
		Lock components in storage	Adjustable straps, hand operated compartment locks
7.9 INSPECT FOR ENTRY			
Activate power circuits for RMS	RMS control station	Proceed to payload work platform	Handholds, etc.
Prepare for detail inspection of payload bay	CCTV camera on RMS, light source on RMS, CCTV in payload bay	Inspect payload items for proper entry fastening	Portable light
Inspect all payload mechanisms and attachments	CCTV, light source, RMS control station, PSS control station		
7.10 INSTALL SHORTING PLUGS			
Activate shorting plug install circuit	PSS control console	Proceed to shorting plug storage location	Handholds, etc.
Provide visual display of shorting plug mechanism	CCTV in payload bay	Remove plug and install in payload receptacle	Shorting plug with handle
Operate shorting plug mechanism	Electromechanical installation mechanism	Verify shorting circuit integrity	PSS checkout console
Verify shorting circuit integrity	PSS checkout console		
Shut down circuits	PSS control console		

BASIC SEQUENCE LISTING

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
7.11 POWER DEADFACE AND SWITCHOVER			
Activate power switchover circuit	PSS control console	Proceed to switchover device location	Handholds, tethers, etc.
Operate switchover mechanism	Electromechanical switch operating mechanism	Operate switchover device	Level handle mechanism
Verify switchover	Event sensing microswitch and display	Verify switch position	(Visual inspection) light source, pin lock and lever mechanism
Shut down circuit	PSS control console		
7.12 DRAIN/PURGE FLUID SYSTEMS			
Activate vent/purge control circuits	PSS control console	Proceed to vent valve location	Handholds, tethers, work platform, etc.
Connect vent piping to orbiter vent system	Electromechanical umbilical operating mechanism, gear motor valve operator	Connect vent piping to orbiter vent system	Hand lever valve
Operate system vent valve	Solenoid operated vent	Operate system vent valve	Hand lever valve
Verify system pressure released	Pressure transducer and PSS display	Verify system pressure release	Pressure gauge on tank
Shut down circuits	PSS control console		

III. REPRESENTATIVE PAYLOAD DESIGN AND OPERATIONS ANALYSIS

3.1 INTRODUCTION

This section describes the results of the design and operations analyses of the 13 representative payloads. The purpose of the design analysis was to develop the technical data needed to determine the cost savings associated with the EVA-oriented payload designs. The design analyses began with a functional analysis and identification of all major elements of each representative baseline payload. Where necessary, additional detail data were developed to bring all representative baseline payloads to the same level of definition. Then, EVA applications were identified and designs of the EVA-oriented payloads prepared. These data formed the input to the comparative cost analysis described in Section IV.

Guidelines adopted for this activity included the following:

1. In the EVA-oriented designs, retain the basic design approach of the current baseline payloads.

2. Assume that redundancy would be included in the design of mechanisms for the automated operational mode and that repeatable devices would be used rather than "one-shot" actuators.

3. Assume that automated designs would continue to require high reliability components for both payloads and orbital support equipment, especially free flying spacecraft.

Baseline payload designs were derived principally from concepts summarized in the Shuttle System Payload Description Study (SSPD). (Exceptions are noted in payload operations definitions.)

A complete WBS-oriented hardware listing was prepared for each payload to establish the basis for the subsequent costing and comparison. At least two levels of data were established with third or fourth levels being defined whenever there were significant differences between the baseline and EVA alternatives. More detailed data are included in Section IV of this report.

The operations analyses were performed for two purposes. First, they supported the design analyses by providing insight into payload functional requirements. Second, they led to baseline-to-EVA comparisons of the mission and crew times required to carry out payload operations. Each of the four mission types (delivery, retrieval, maintenance, and sortie) are described separately as appropriate for the particular representative payload. Payload delivery missions apply to all of the automated (free-flying) spacecraft. Retrieval operations apply normally only to the payloads (EOS, LST, MFM, DOM) classified as reusable. Similarly, maintenance missions can only be performed

on those representative payloads designed for retrieval and on-orbit servicing; namely, EOS and LST. A summary of mission data and the required orbital characteristics for the 13 representative payloads is shown in Table 3-1.

Table 3-1. Representative Payload Missions Data

SPACECRAFT-SORTIE PAYLOAD					SIZE			ORBIT			SHUTTLE ORBIT			P/L*	STAGE REQMTS		
Traffic Model No.	SSPD No.	WBS No.	Name	Type	Weight (kg)	Dia. (m)	Length (m)	Apogee (km)	Perigee (km)	Incl. (deg)	Apogee (km)	Perigee (km)	Incl. (deg)	Weight (kg)	Shuttle to OOI	OOI to Shuttle	STAGE
EO-3	EO-8	11	Earth Observ. Sat.	LCR	3997	3.89	11.3	914	914	99.15	185	185	99.15	6530	X	X	Integral
PHY-2A	AP-04	12	Gravity & Relativity Satellite	LCE	602	1.8x1.8	4.1	938	938	90	185	185	90	4315	X	-	Burner IIA
AST-6	AS-01	13	Large Space Telescope	CDR	9574	3.96	12.7	520	520	28.5	520	520	28.5	9909	-	-	-
EOP-6	OP-03	14	Mini LAGEOS**	CDE	102 (ea) (2 Del'd)	0.5	sphere	650	650	28.5, 55, 90	650	650	28.5, 55, 90	410(2)	-	-	-
EOP-9	OP-06	15	Magnetic Field Mon.	LCR	266	2.3	5.59	1500	1500	28.5	400	400	28.5	961	X	X	Burner IIA
PH-1C	AP-03	16	High Alt. Explorer	LCE	448	3.14	2.0	1 AU	-	ECL	400	400	28.5	1151	X		Delta
NN D-2C	CN-58	17	U.S. DOMSAT "C" (TDRS)	CDR	310 (ea) (3 Del'd)	2.46	6.85	35,786	35,786	~ 0	296	296	28.5	510 (3 ea.)	X	X	Delta
EOP-4	OP-01	18	Geopause	CDE	789	2.1	2.5	30,000	30,000	90	278	278	90	1495	X	-	Delta
PL-19	PL-12	19	Mariner Jupiter Orbiter	CDF	2491	3.96	5.8	ESC	-	-	185	185	28.5		X	-	Centaur
AST-10	AS-01	21	1.5m Infrared Telesc.	Sortie	3997	4.6	8.86	400	400	28.5	400	400	28.5	5767	-	-	-
PHY-7	AP-06	22	Atmospheric, Magnetospheric and Plasmas in Space	Sortie	9723	4.6	18.2	340	340	90	340	340	90	17,515	-	-	-
ST-2	ST-23	23	Adv. Tech. Lab	Sortie	4479	4.6	15.9	370	370	60	370	370	60	7429	-	-	-
ST-2	ST-04	24	Phys. & Chem. Fac.	Sortie	809	4.6	15.2	500	500	55	500	500	55	7860	-	-	-

*Shuttle installation consisting of spacecraft/payload (flight systems) and orbital support unit. Does not include staging unit.

**Two spacecraft deliveries to each inclination.

OOI = Operational Orbit Insertion
OO = Operational Orbit
ECL = Ecliptic
ESC = Escape

The remainder of this section is organized into subsections, each of which treats a representative payload. Within each representative payload subsection, there is a description of the baseline system and program and a detailed discussion of mission operations. These are followed by summaries of the EVA applications associated with the representative payload. The conclusion of each representative payload subsection is a detailed description of the results of the operations analysis performed, including comparisons of the operational sequences and timelines for representative payload operations in the baseline and EVA-oriented modes.

Operations were analyzed for each payload individually during the study. However, owing to the extensive similarities, only generalized diagrams were prepared, as shown in Figures 3-1 and 3-2. However, a discussion is provided with each payload relative to the operations flow.

The objective of timeline analysis is to help determine the feasibility of the suggested EVA substitutation for automated payload components and the related payload support mechanisms. The analysis performed for each representative payload includes estimating the time intervals required in the automated mode and the EVA mode to perform the selected functions for which equipment modifications or deletions have been suggested. Also, the individual tasks need to be integrated into a mission timeline that covers the total on-orbit activity sequence being compared. A prime example is the sequence involving

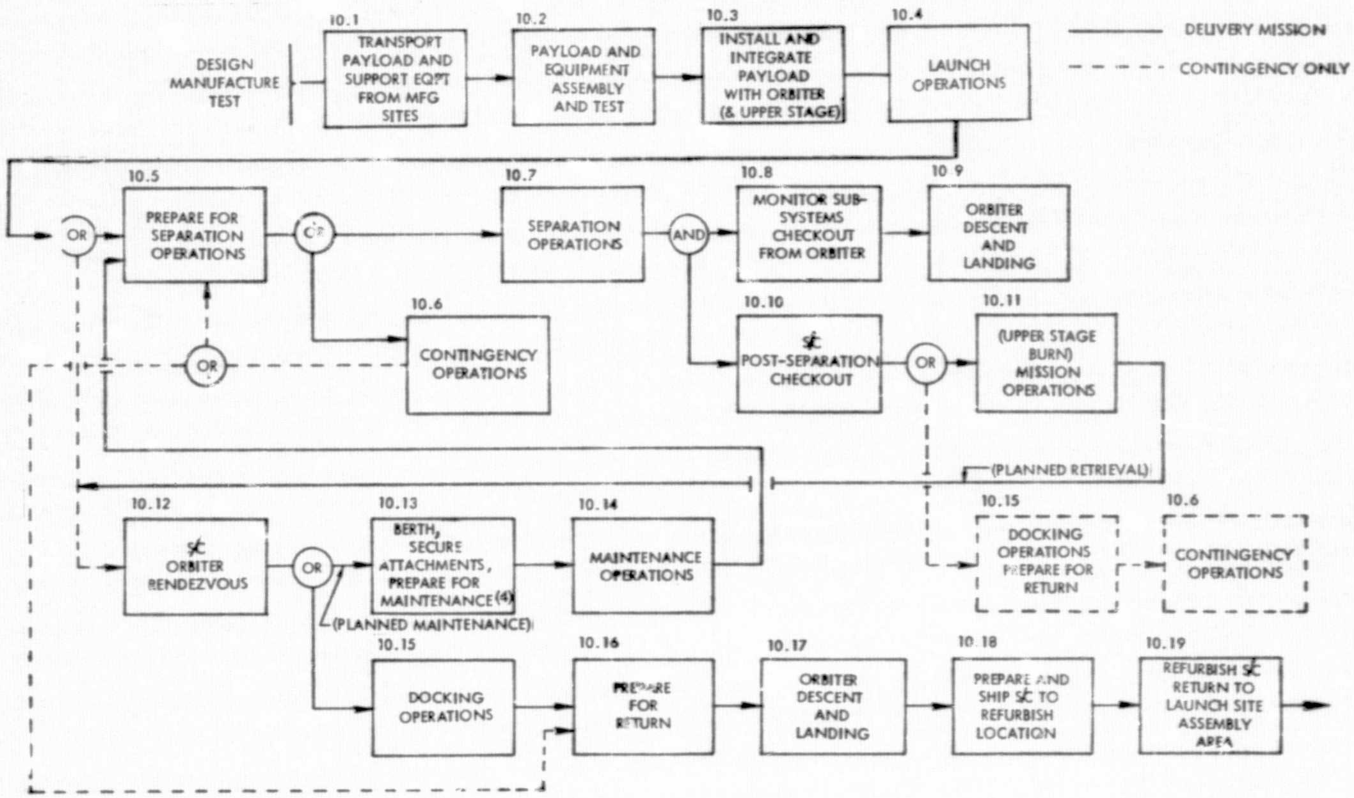


Figure 3-1. Automated Spacecraft - Operations Cycle

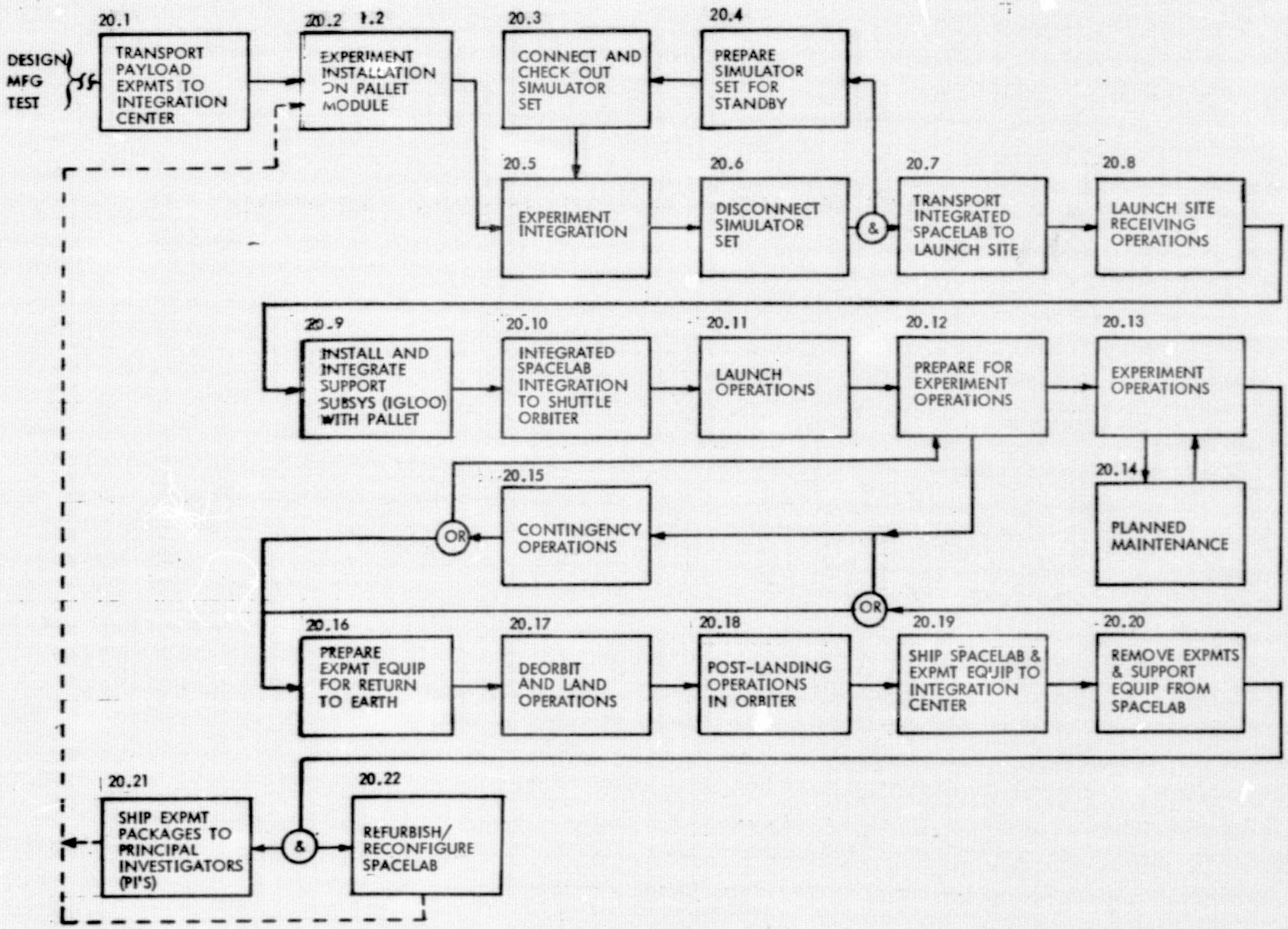


Figure 3-2. Sortie Payload - Operations Cycle

the preparation of the automated payloads for separation. This sequence applies to the nine automated payloads of the representative group.

It was estimated that in most cases performing a mission function segment by EVA would require a somewhat longer time interval than the equivalent function performed by the automated mechanisms. However, the results show several cases with equal or nearly equal times, and for MJO, the EVA time is slightly less if EVA preparation time is excluded. All timelines and crew duty cycles fit within Shuttle and mission constraints except as follows:

P/L - Mode	"Cabin" Crew Duty Cycle	EVA Crew Duty Cycle
GRS - EVA	3.5-hr delay from normal	2nd EVA after 8 hours rest
LST - B/L	2nd shift required	
- EVA	2nd shift required	2nd EVA occurs during normal off-duty period
HAE - B/L	Requires 2nd shift, 3.5-hour delay in normal shift, or shutdown of C/O and resumption 12 hours later	
- EVA	Same	2nd EVA occurs during normal off-duty period

These exceptions are either simple operational work arounds, or, in the case of the LST, a planned second shift. The term "normal shift" refers to the basic Shuttle timeline presented earlier. Timelines for the automated spacecraft later in this section show total elapsed time from start of operations (i.e., Time = 0) for both automated and manual activities. Crew size estimates reflect task sequences for two men operating PS and RMS controls for the baseline concept; the same two men plus one man EVA for the manual concept (Mini-LAGEOS is the exception) for auto spacecraft. The crew size and number of EVA's are well within the baseline Shuttle provisions.

Sortie payload timlines show similar data. In one sortie payload case, Physics and Chemistry Facility, use of Spacelab Module airlocks impacts preparations such that EVA takes less total time than the baseline. The baseline and EVA timelines meet all Shuttle and mission constraints for sortie payloads. Sortie payload timelines required two men EVA for the ATL payload only. Activity sequence numbers are shown as pertinent after bars on the timelines.

The assumptions used in the present study are given in Table 3-2.

Table 3-2. Timeline Ground Rules and Assumptions

A	Zero time for both EVA and automated modes of operation for experiment payload pre-operations start after the Shuttle orbiter has been established in its operational orbit, including navigation updates.
B	Payload/EVA crew may initiate preparation activities prior to zero time.
C	Orbiter crew is rested and ready to perform up to a 12-hour normal work period at time zero.
D	EVA crew requires 3 hours of pure oxygen pre-breathing prior to pressure drop to 4 psi (see Figure 2-21). Other limited inside cabin activities may be scheduled during first 2 of the 3 hours.
E	The EVA crew can be in space suits up to approximately 6 hours.
F	The last hour of pre-breathing is used for space suit donning and other preparations for EVA. This hour is counted as part of the total task time for the man-hour summary comparisons. However, this hour does not necessarily delay payload preparation.
G	No space-suited rescue standby crew is required as backup for EVA crew in the payload bay.
H	EVA activities are scheduled only while spacecraft remains attached to the orbiter.
I	No mechanized EVA maneuvering aids were used (e.g., remote maneuvering unit, cherry picker, etc.) but could be used to improve some EVA activities.
J	Required EVA hand-holds, rails, foot restraints, work platforms, etc., were included in design analysis for the efficient accomplishment of EVA tasks.
K	Only one orbiter RMS will be used for both automated or EVA modes of activity.
L	The EVA crew will require a minimum of 12 hours inside time between successive EVA periods.

3.2 EARTH OBSERVATORY SATELLITE

Figure 3-3 presents the baseline design concept for the Earth Observatory Satellite (EOS) payload. This payload exemplifies a low cost reusable design. The figure shows the payload installed in the orbiter together with the concept of an automated module exchange mechanism for on-orbit servicing. The figure also illustrates the "modularity" concept for the EOS. The objectives of the EOS program are to continue a wide ranging program of earth observations to support the long range goals of scientific disciplines such as agriculture, geology, meteorology, hydrology, and oceanography.

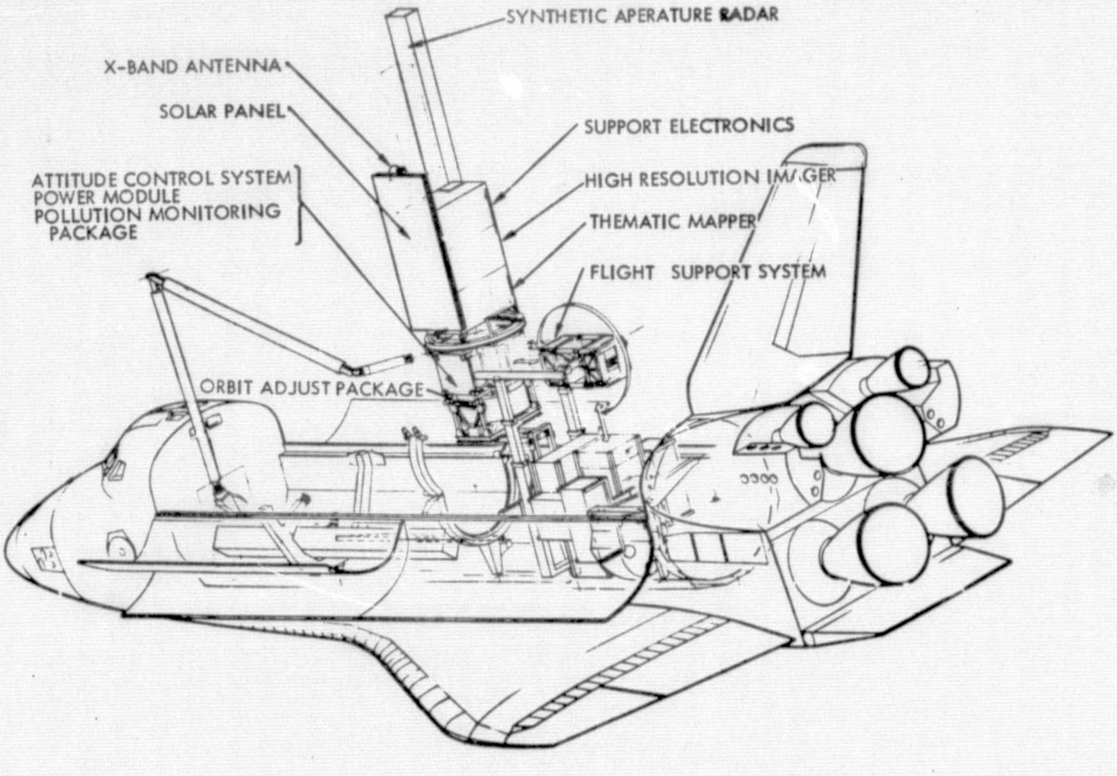


Figure 3-3. EOS and Flight Support System

Major payload sensors for the representative EOS include the (1) thematic mapper, (2) radar imager, (3) high resolution imager, and (4) pollution monitoring package. The on-orbit support equipment consists of two major elements, the (1) payload retention and positioning system which holds the payload in the orbiter during ascent and then rotates the payload out of the payload bay, and (2) the special purpose manipulator system which is used for module exchange on servicing missions.

3.2.1 Baseline Payload Operations Definition

The EOS program will operate a sequence of satellites in sun synchronous orbits starting in 1979. The EOS is classified as a low cost reusable spacecraft. Seven delivery, four servicing missions and five retrieval missions are planned for the 1980-1991 time period using three operational satellites. Earlier launches will be made with expendable launch vehicles but all later deliveries, servicing, and retrievals will be Shuttle operations.

The automated approach to EOS activation and checkout will start with preparation of the orbiter payload specialist station (PSS). A visual check of the payload will be made using closed circuit television installations in the orbiter bay and on the remote manipulator system. Checkout of certain payload sensors and subsystems will be made while the payload is in the stowed position. The positioning platform will then be attached to the payload, the payload retention frame will be released, and the payload rotated out of the orbiter bay to a vertical position. Solar panel erection and unfolding and radar antenna extension will be verified. These items will be returned to a stowed configuration prior to payload boost to operational orbit. Contamination shields will be removed from payload subsystem optical components.

After completion of payload checkout, the RMS will be attached to the payload, the positioning platform latches will be released and the payload extended and oriented by the RMS. After RMS release, the orbiter will separate from the payload. EOS preparation and separation operations are estimated to require approximately 3.5 hours. Further activities involving orbiter and payload include monitoring of payload free-flight checkout operations (possibly conducted by ground control) and monitoring of payload propulsion to its operational orbit. If free-flight checkout should reveal payload anomalies, the spacecraft would be recovered and returned to earth for corrective action if the automated recheck cannot reveal items which can be remedied by the automated systems. EVA may be utilized in contingency situations.

Maintenance Missions

The EOS flight support system (FSS) concept has been developed to provide an automated on-orbit servicing system for payloads designed for reuse. The basic concept of the FSS is the exchange of major modules of the spacecraft subsystems and mission (payload sensors) equipment. The FSS concept presently under study has been specifically developed for the current EOS spacecraft concept designed with exchangeable modules.

The automated routine of EOS capture and docking operations begin with preparation of the FSS and RMS control. The boost locks on the FSS will be released and the payload positioning platform rotated to the vertical orientation to receive the EOS. The orbiter RMS will be attached to the EOS and the EOS maneuvered into position to be captured by the positioning platform docking latches. During capture of the EOS, the shuttle-to-payload umbilicals will automatically be attached.

The planned maintenance operations will begin with a visual inspection of the spacecraft using the RMS and orbiter installed CCTV units. Protective covers will be installed over contamination sensitive payload surfaces and safety items such as pyro shorting plugs also will be installed by activation of the payload automated components. Sensors will be cleaned as required and as possible by automated servicing devices.

Major maintenance functions will be performed by the FSS module exchange mechanism (MEM). The appropriate spare modules in the FSS storage compartment will be removed by the MEM, elevated to the payload module position where the MEM will withdraw the used module, replace it with the new module, and then return the expended module to the storage compartment. The procedure will then be repeated until all the required payload module replacements have been accomplished. Certain EOS payload component replacements (e.g., the radar antenna) will require the use of the RMS in the component interchange.

Other activities to be accomplished in typical baseline EOS servicing missions may include limited repair of mechanical items and servicing of fluid systems, probably by exchange of fluid containers.

Retrieval Missions

After the planned EOS mission is completed or after an EOS system malfunction for which on-orbit maintenance is not practical, the spacecraft will be retrieved and returned to earth for major refurbishment activities. The EOS capture and docking operations for retrieval will generally be identical to that of the similar activity of the routine servicing missions. Potential variations could be caused by EOS subsystem malfunctions that would prevent a fully cooperative EOS during the capture and docking. The spacecraft capability to return to the EOS-orbiter rendezvous will, however, usually assure the capability of a routine capture.

The prepare-for-return operations will require the automated return of the spacecraft to its stowed position within the orbiter bay using the FSS. Prior to this, all extended antennas, arrays, and mechanisms will be retracted (or removed if necessary), shorting plugs installed, all fluid drain and purge operations accomplished and visual inspection of the spacecraft performed. After rotation of the EOS into the orbiter bay the payload retention system will be attached and latched. Other entry latches will be engaged and contamination shields installed.

After the orbiter descent and landing, the EOS spacecraft will be removed and routed to the proper facilities for refurbishment and preparation for the following flight. The FSS also will be refurbished as required.

3.2.2 EVA Applications

The EVA-oriented design and operations for EOS maintain the design and function of the baseline automated flight support system as well as that of the spacecraft itself. A simplified concept utilizing only RMS and manual module exchange was also defined to evaluate potential cost savings in payload servicing using EVA.

Several of the EOS EVA applications are illustrated in Figure 3-4. Two functions are performed in the stowed position. A current concept for the EOS provides primary support of the spacecraft by a retention ring during launch and ascent to orbit. The proposed EVA activity is to use a portable power tool to drive a mechanism for unlatching the retention ring (center sketch) and then move the tool to side positions to operate mechanisms for swinging the ring

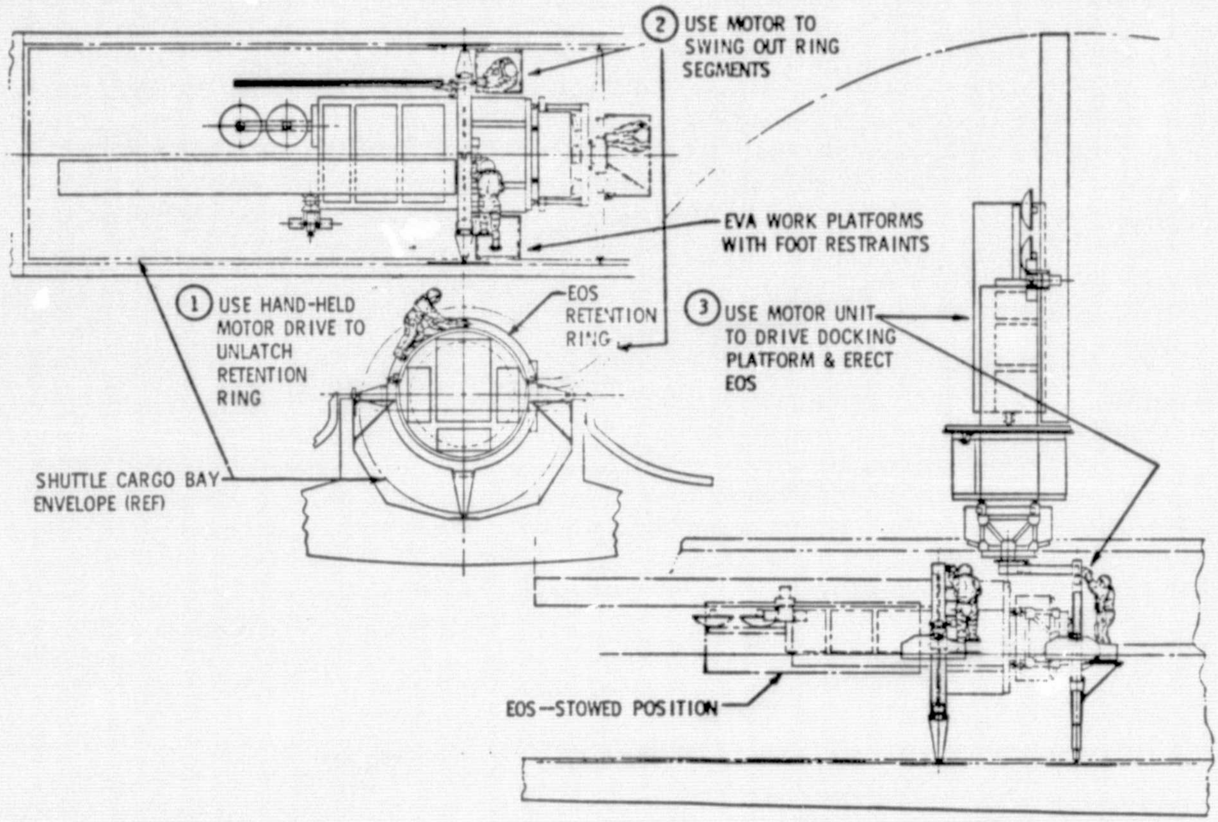


Figure 3-4. Typical EOS EVA Applications

segments out of the way (top sketch). The setup for the portable motor drive would include brackets to counteract the drive torques during operation.

The third activity illustrates operation of the deployment device (positioning platform) and is shown in the lower sketch. The EVA concept for this operation would be to use the same portable power tool to rotate the EOS platform (and attached EOS) out of the orbiter payload bay into a payload release position. These functions could be performed by EVA as either a primary mode or as a backup.

The suited EVA crew many be required to use closed-circuit life support umbilicals rather than the more conventional "back pack" design in order to reduce potential contamination of EOS sensors prior to release from the orbiter. Present Shuttle provided EVA operations are on the basis of vented space suits. The "clean" type life support for the EVA crew then may be an extra charge to the EVA system should later analyses confirm the requirement for the minimized environment contamination. It also should be noted that the sketches show the addition of payload chargeable work platforms for EVA crew retention during the proposed EVA activities.

The automated and EVA operational mode hardware requirements for the previously illustrated EVA applications are shown in the figure. The EOS is mounted within a retention ring as shown previously. This ring is divided in

movable segments which can swing clear to allow spacecraft rotation out of the payload bay. The figure summarizes the estimated automated and EVA hardware required for the ring center opening latch and the hardware for the segment rotation. For these functions the automated hardware includes motor and screw actuators, limit switches, and displays.

Delivery Missions

Preliminary payload activation and checkout are the same in the EVA modes as in the automated mode of operations. EVA activities are substituted for automated device operations in the release of boost latches and monitoring of the checkout of mechanical systems.

The major EVA substitutions in payload activation operations involve EVA utilization of a portable power tool in place of built-in automated mechanisms in the release of the payload retention frame and in the rotation of the payload positioning platform. The deployment of the payload and the separation from the orbiter will be accomplished in the same manner as with the automated system.

Maintenance Missions

The EVA-oriented approach to EOS maintenance utilizes the portable power tool to perform positioning platform movement.

Monitoring and alignment adjustments will be performed by the EVA astronaut in the module exchange operations. A design concept for manual replacement of the communication antenna on the EOS resulted in simplified mechanization compared with baseline RMS operations. EVA capability also is better able to cope with minor repairs and adjustments discovered during detailed visual inspection of the spacecraft.

The "prepare for separation" and "separation" operations after the completion of the planned maintenance are the same as for the delivery mission.

Retrieval Missions

The retrieval operations are the same as those required for servicing operations described above. The "prepare for return" operations utilize manual operating latches for securing the payload and appendages for entry. EVA inspection and installation of contamination shields and safety devices replace the automated systems for these activities.

3.2.3 Operations Analysis

Operations Cycle

The first level operation cycle block diagram for the EOS is shown in Figure 3-1. The three basic types, (1) delivery, (2) service or maintenance, and (3) retrieval, are shown as alternative paths on the diagram. The potential effects of on-orbit contingencies in preparation for separation or free-flight checkout operations are indicated.

Substitution of EVA operations for functions ordinarily performed by electromechanical devices can affect program cost areas for activities preceding those shown in the conventional operations cycle. This is indicated in the diagram by the "design, manufacture, test" notation in the upper left-hand corner. Ground operations prior to the EOS payload delivery or service/retrieval launches are shown in the first three blocks of the diagram, 10.1, 10.2, and 10.3

Post-landing operations for the EOS program are simply noted by blocks 10.18 and 10.19 on the diagram. These operations can vary considerably depending on the particular EOS mission. For the delivery and servicing missions, the post-landing operations will probably be confined to the launch complex where the spacecraft flight support system will be removed from the orbiter, stored until the next scheduled reuse, and then prepared for the next EOS mission.

For retrieval missions, the returned EOS must be removed and sent to the refurbishment center selected for this operation. The EOS will then be returned to the launch site as indicated by block 10.1 of the diagram where it will undergo the preflight and launch operations again. The flight support system will be refurbished and reused as indicated for the delivery and servicing missions.

Sequence Comparisons

The on-orbit operational sequence comparisons for the EOS delivery missions are summarized in Table 3-3. It will be noted that many of the activity comparison details are referenced to the basic sequence table shown in Section II. From the analysis of the activity sequence comparisons and other factors the following functions were selected as those for which comparative designs and cost comparisons were generated:

1. FSS cradle arm segment latch/unlatch
2. FSS cradle arm segment rotation, two ways
3. FSS positioning platform rotation, two ways
4. Orbiter to spacecraft umbilical disconnect/connect
5. Release/reconnect payload extendibles boost locks
6. Release/reconnect FSS boost locks
7. Extend/retract payload extendibles (solar array, radar antenna)
8. Remove/replace sensor contamination shields

Timeline Comparisons

The operations analysis included the development of on-orbit operations timelines for the baseline representative payload designs and for the EVA alternative designs. Figure 3-5 shows the EOS delivery mission times and Figure 3-6 shows a similar comparison for the EOS maintenance mission. Since the maintenance mission encompasses a retrieval operation, no separate timeline was prepared. The timelines were prepared from the preceding activity sequences with task times derived from Skylab experience or from prior studies as discussed in Section II.

Table 3-3.
EARTH OBSERVATORY SATELLITE (EOS)
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
1. PRE-OPERATIONS			
1.1 REMOVE CONTAMINATION SHIELDS (Star tracker, thematic mapper, high resolution imager, pollution monitor sensors)			
Basic sequences			
1.2 DISENGAGE APPENDAGE BOOST LOCKS (Solar panel, radar antenna)			
Basic sequences			
1.3.2 ERECT SOLAR ARRAY (Three-section solar panel)			
(Solar array not fully deployed until spacecraft boosted to operational altitude in baseline system, deploy for test)		Proceed to work platform	Work platform, foot restraints, handholds, tethers
		Verify all clear	On-site inspection
Activate power circuits	PSS control console	Unfold and lock solar panel sections in open position	Manual handholds on panel, manual locks for opened panels
Provide visual display of operations	CCTV, display	Verify erection latch operations	PSS console, checkout console, on-site inspection
Operate solar array erection mechanism	PSS control console, electro-mechanical mechanismddrive	Power down circuits	PSS
Operate solar array unfold mechanism	Electromechanical mechanism drive		
Verify operation	CCTV		
Store solar array for flight	CCTV, electromechanical drive		
Latch solar array for flight	Electromechanical latch		
Power down circuits	PSS control console		
1.3.1 ERECT ANTENNA (Imaging Radar)			
Verify all clear	CCTV in payload bay	Proceed to work station	Work platform, handholds, foot restraints
Activate power cricuit for radar panel erect mechanism	PSS control console	Verify all clear	On-site inspection
Operate radar antenna deployment system	Electric gearmotor mechanism	Rotate radar antenna to operating position	Automated operating radar antenna rotation mechanism
Verify completion of deployment	Event sensing microswitch, CCTV	Verify completion of deployment	On-site inspection
Return antenna to stored position	Electric gearmotor mechanism	Return antenna to stored position	PSS control console
Power down circuits	PSS control console	Power down circuits	PSS control console
1.4 OPERATE DEPLOYMENT DEVICE (Payload retention and positioning system)			
Activate payload retention and positioning system circuits	PSS control console	Activate payload retention and positioning system circuits	PSS control console
Verify all clear for payload deployment	CCTV in payload bay	Proceed to EOS retention ring latch	Work platform, handholds

Table 3-3. (continued)

EARTH OBSERVATORY SATELLITE (EOS)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
Operate payload retention latch release mechanism	Electric gearmotor latch mechanism	Release retention ring latch	Manual operating latch mechanism
Operate payload retention ring segment rotation	Electric rotation mechanism drive	Rotate retention ring segments to clear EOS	Manual operating segment rotation mechanism
Verify retention ring segment rotation complete	Event sensing microswitch, CCTV	Verify all clear for EOS erection	On-site inspection
Release boost locks on docking platform	Electromechanical latches	Release boost locks on docking platform	Manual operating latches
Operate docking platform rotation mechanism to erect EOS	Electric gearmotor	Rotate docking platform to place EOS in vertical position	Hand held portable motor to operate rotation mechanism
Operate RMS and attach to EOS for deployment	RMS control console	Attach RMS to EOS for deployment	RMS control console, EVA direction and guidance
Release docking platform to EOS retention devices	Electromechanical latches	Release docking platform to EOS retention devices	Manual operating latches
1.8 TEST/CHECKOUT (Instrumentation and subsystems)			
Basic sequences			
1.10 VISUAL INSPECTION (Pre-release inspection)			
Basic sequences			
4. SEPARATE SPACECRAFT			
4.1 REMOVE UMBILICALS (Orbiter to spacecraft)			
Umbilical removal accomplished as part of FSS operations			
4.2 DISENGAGE SPACECRAFT			
Activate RMS	RMS control console	Proceed to position for observing spacecraft deployment	Handholds, tethers
Release docking mechanism latches	PSS contol console, electromechanical latches	Observe automated RMS sequence	Verbal comments to RMS control
Verify latch release	Event sensing microswitches		
Move spacecraft from docking platform to extended RMS position	RMS control console		
Align SC to correct orientation	RMS control console		
Release RMS end effector grip, impart separation velocity	RMS control console		
Return RMS to stowed position			
Power down circuits			
4.3 TRANSFER TO SPACECRAFT GROUND			
Transfer accomplished as part of FSS operations			

Table 3-3. (continued)
EARTH OBSERVATORY SATELLITE (EOS)
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
5. DOCKING OPERATIONS			
Basic sequences			
6. PLANNED MAINTENANCE			
6.1 INSTALL PROTECTIVE COVERS (Star tracker, thematic mapper, high resolution imager, pollution monitor sensors)			
Activate power circuits for protective cover installation	PSS control console	Proceed to spacecraft locations	Handholds, tethers
Provide visual display of operation	CCTV	Remove covers from storage	Storage compartment
Operate protective cover installation mechanisms	Electromechanical cover rotation mechanisms	Place covers over sensors	Manual operation
Verify cover installation complete	Event sensing microswitches	Verify cover installation complete	Visual inspection
Power down cover installation circuits	PSS control console		
6.2 INSTALL SAFETY ITEMS (Pyro shorting plugs, covers)			
Activate pyro shorting plug installation circuit	PSS control console	Proceed to spacecraft pyro short plug area	Handholds, tethers
Provide visual display of sequence	CCTV	Perform pyro shorting plug install operation	Manual operating shorting plug
Operate pyro shorting plug installation device	Electromechanical plug install device	Verify installation complete	On-site inspection, PSS checkout console
Verify installation complete	Event sensing microswitches, display, PSS checkout console		
Power down circuits	PSS control console		
6.3 INSPECT SPACECRAFT			
Activate RMS and sensor	RMS control station	Proceed to spacecraft	Handholds
Provide visual display of spacecraft exterior	CCTV in payload bay and RMS, light source	Inspect spacecraft for potential service and repair	On-site inspection, work platforms, light source
Inspect spacecraft exterior for anomalies	PSS display console	Report the potential repairs	Communication systems with PSS
Record observations of potential service and repair requirements	PSS		
Power down systems	PSS control console, RMS control station		
6.4 ACCESS SPACECRAFT AND SPARES (Components required for planned maintenance and changes planned per inspection)			
Activate RMS and maintenance end effector	RMS control station	Proceed to spares storage area	Handholds, tethers, etc.
Activate spares storage release mechanism circuits	PSS control station	Open storage cover and unlatch restraints on required replacement equipment	Hand level mechanisms

Table 3-3. (continued)

EARTH OBSERVATORY SATELLITE (EOS)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
Open spares storage container	Electromechanical latch, gear motor cover rotation device	Remove spacecraft component covers as required	Hand tools
Exchange non-standard components as required	RMS and special end effectors		
Provide visual display of activities	CCTV in payload bay and on RMS		
6.5 REMOVE AND REPLACE			
Remove spacecraft module	Flight support system (FSS)	Proceed to component storage area	Handholds, etc.
Transfer removed module to storage	FSS	Obtain new component	Manual operation
Transfer new module to spacecraft, insert	FSS	Remove old component, secure temporarily, install new component, replace spacecraft cover	Manual operation, hand tools
Repeat above steps as required	FSS	Repeat above steps as required	Hand tools
Check integrity of subsystems affected	PSS checkout console	Store and secure all replaced parts	Hand latch mechanisms
6.7 CLEAN SENSORS			
Activate circuits	PSS control console	Proceed to work station	Handholds, etc.
Operate sensor cleaning technique (built-in devices)	Gas jets, mechanical cleaners	Clean sensors	Portable gas jets, lens brush, etc.
Power down circuits	PSS		
6.8 REPAIR MECHANICAL ITEMS (Items as required per inspection)			
		Remove malfunctioning item	Hand tools
		Transfer to apllet work sta.	Handholds
		Repair mechanical items	Work bench, hand tools
		Return item to spacecraft and install	Hand tools
		Check operations	PSS control console, on-site inspection
6.9 SERVICE PROPULSION MODULE (Orbit adjust, attitude control)			
Place payload in retention cradle, fasten	Payload positioning system swing arm motors, electromechanical latch	Place payload in retention cradle, secure	Payload positioning system manual operating ring segment and locking latch
Release payload position system latches	PSS control console electromechanical latches	Release payload positioning system latches	Manual operating latches
Release propulsion module retention latches	RMS control console, end effector	Release propulsion module retention latches	Manual operating latches
Remove propulsion module from payload, move to storage	RMS	Remove propulsion module from payload, move to storage	RMS

Table 3-3. (continued)

EARTH OBSERVATORY SATELLITE (EOS)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
Transfer new propulsion module from storage to payload	RMS	Transfer new propulsion module from storage to payload	RMS
Fasten propulsion module to payload	RMS, end effector	Secure propulsion module to payload	Manual operating latches
Verify system	PSS checkout console	Verify system	PSS checkout console, on-site inspection
7. PREPARE FOR RETURN			
Basic sequences			

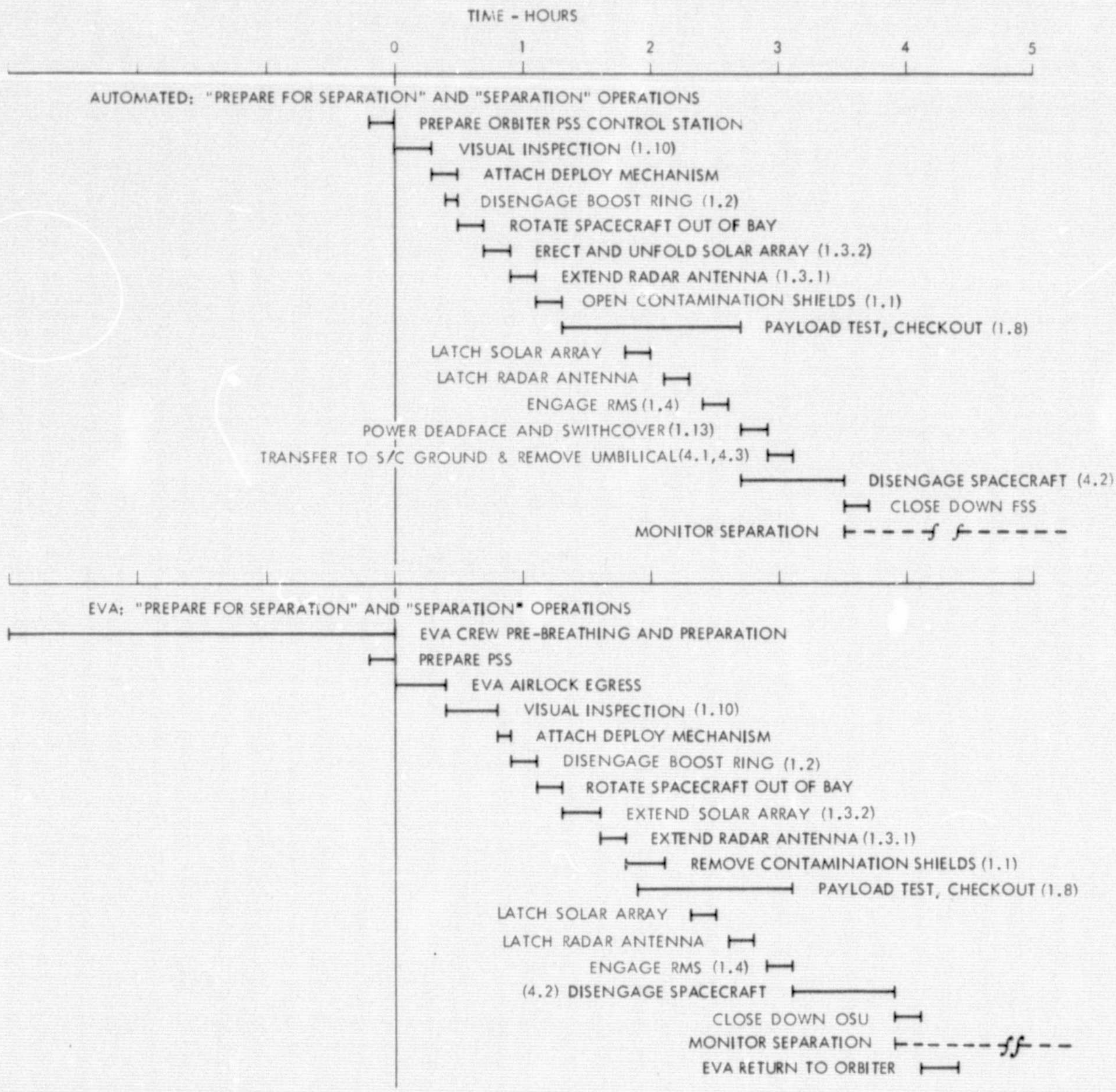


Figure 3-5. EOS - Preparation for Operation Baseline and EVA Modes

Figure 3-6. EOS - Docking, Planned Maintenance and Separation Operations Baseline and EVA Modes

The "zero" starting point for the timelines was selected as the time when payload supporting activities in the orbiter bay begin. Thus, the variations in preparation time such as Payload Specialist Station (PSS) checkout and the EVA crew prebreathing and in-cabin preparation occurred prior to T=0. The crew preparation time could be combined with certain other tasks and vary with mission type as previously described.

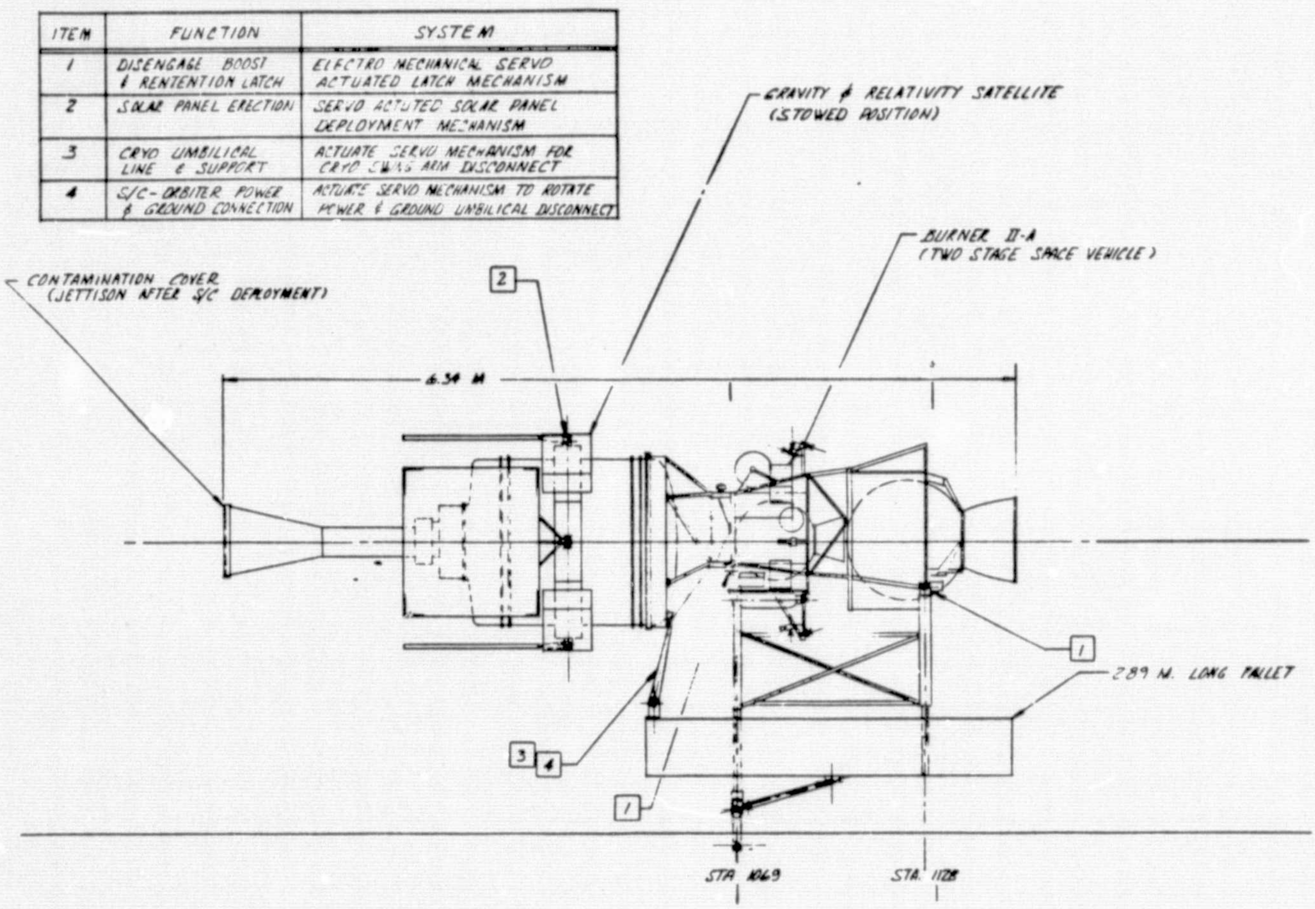
The delivery mission timeline for the EOS baseline system was estimated to require approximately 3.5 hours from the initial visual inspection (via CCTV) to the disengagement of the spacecraft. The automated test and checkout of the payload was defined by an in-house study at approximately 1.4 hours. Thus, the baseline delivery time excluding checkout is 2.1 hours. The comparable duration for the EVA-oriented EOS system is 2.6 hours excluding checkout with a total time of approximately 3.9 hours to the disengagement of the spacecraft. It will be noted that for this payload certain activities can be and are performed in parallel with the payload checkout and some EVA activities are indicated subsequent to the spacecraft separation. These post-separation EVA activities are performed on the flight support system.

The timeline comparison estimates for a typical EOS maintenance mission are illustrated in Figure 3-6. A wide variety of repair, service, and maintenance activities could be postulated for this type of mission. The case shown is for a relatively low level of maintenance activity. The total mission times shown on the figure are 4.3 hours for the baseline and 5.3 hours for the EVA system. The time estimates for capturing the EOS and setting up for the maintenance activities are 0.9 hour for the baseline and 1.3 hours for the EVA-assisted operations. The total mission times are 4.3 and 5.3 hours.

The timelines for the EOS retrieval missions will be similar to the spacecraft recovery portion of the maintenance mission. Additional times, allocated for preparation for return activities, are itemized in the basic sequence comparisons (Section II).

3.3 GRAVITY AND RELATIVITY SATELLITE

Figure 3-7 presents the baseline design concept for the Gravity and Relativity Satellite (GRS) payload. The payload is classified in the NASA traffic model, TMX 64751, as a low cost expendable design. The figure shows the spacecraft attached to a two-stage upper stage (Burner II-A) for boosting the spacecraft from the Shuttle orbit to the payload operational orbit and circularizing. The stage, in turn, is shown attached to a Spacelab pallet by a tubular framework. Item 1 identifies separation points between the frame and the IUS. Item 2 indicates pivot points for the four solar panels (shown in stowed position). Items 3 and 4 show the payload cryogenic vent umbilical and the power and data umbilical attachment



ITEM	FUNCTION	SYSTEM
1	DISENGAGE BOOST & RENTENTION LATCH	ELECTRO MECHANICAL SERVO ACTUATED LATCH MECHANISM
2	SOLAR PANEL ERECTION	SERVO ACTUTED SOLAR PANEL DEPLOYMENT MECHANISM
3	CRYO UMBILICAL LINE & SUPPORT	ACTUATE SERVO MECHANISM FOR CRYO SWING ARM DISCONNECT
4	S/C-ORBITER POWER & GROUND CONNECTION	ACTUATE SERVO MECHANISM TO ROTATE POWER & GROUND UMBILICAL DISCONNECT

Figure 3-7. Baseline GRS Payload

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The major payload sensors include a precession gyroscope set, star telescope, star tracker, IR earth horizon sensor, and a cryogenic helium dewar.

The GRS program consists of two spacecraft. Desired delivery schedules call for one launch in 1983, the other in 1984. The desired orbital altitude is approximately 940 km. The mission objective of the GRS flights is to test Einstein's general theory of relativity by measuring the precession of orthogonal gyroscopes in earth orbit. Precision optical sensors are required to keep the spacecraft accurately oriented. The cryogenic helium dewar is designed to keep the gyroscopes at approximately 1.6 degrees K for a year.

3.3.1 Baseline Payload Operations Definition

The automated routine of payload activation starts with preparation of the orbiter PSS. Visual checks of the payload will be made using the orbiter installed closed circuit television cameras and PSS displays. Subsystems and mission equipment will be checked. The RMS will be attached to the payload which will then be partially deployed out of the payload bay in order to check the solar panel operations. The solar panels are deployed on the basis that the latches, panel orientation mechanism and other panel structure are stressed for the "g" loading of the kick stage boost to the satellite operational orbit. Use of a Burner II derated kick stage was estimated to result in a maximum thrusting load of approximately 1.3 g.

After completion of mission equipment and subsystem checkout, the GRS will be prepared for release by the automated activation of the power deadface and switchover mechanism, the transfer of electrical circuit ground to the spacecraft, and disconnection of the orbiter-to-spacecraft umbilical. The spacecraft can then be translated by the RMS to the extended position and released, and the orbiter separated from the spacecraft. Further subsystem checks and the departure of the GRS to its operational orbit will be monitored from the orbiter. The orbiter is then free to perform its other mission operations and return to earth.

3.3.2 EVA Application

Several of the satellite and supporting equipment items affected by the recommended EVA operations are highlighted in Figure 3-8. EVA applications identified include payload boost latch release by manually actuated latches, manual erection of the four solar panels, and manual operation of the signal, power, and cryogenic fluid vent umbilical. Manual extension of a star telescope sunshade is an EVA application that provides improvement in orbiter payload volume utilization by the GRS. Manual removal of flight optics contamination covers also was incorporated in the EVA-oriented design of this payload.

3.3.3 Operations Analysis

Operations Cycle

The operations cycle for the GRS payload is summarized in Figure 3-1. The cycle indicates pre-delivery operations, launch site integration, launch operations, and on-orbit preparation and separation operations, with a normal

ITEM	FUNCTION	SYSTEM
1	PAYLOAD BOOST & RELEASE LATCH	MANUAL ACTUATED OVERCENTER LATCH SYSTEM
2	SOLAR PANEL ERECTION OPERATION	SPRING LOADED LATCHES DETENTS & HINGES LANYARDS
3	CRYO UMBILICAL LINE DISCONNECT	MANUAL QUICK DISCONNECT FITTING, FLEX LINE
4	S/C - ORBITER SIGNAL & POWER DISCONNECT	MANUAL ACTUATED CONNECTOR
5	DEPLOY SUNSHADE REMOVE CONT. COVER	MANUAL MOVEMENT, LATCHES & SPRING LOADED PINS

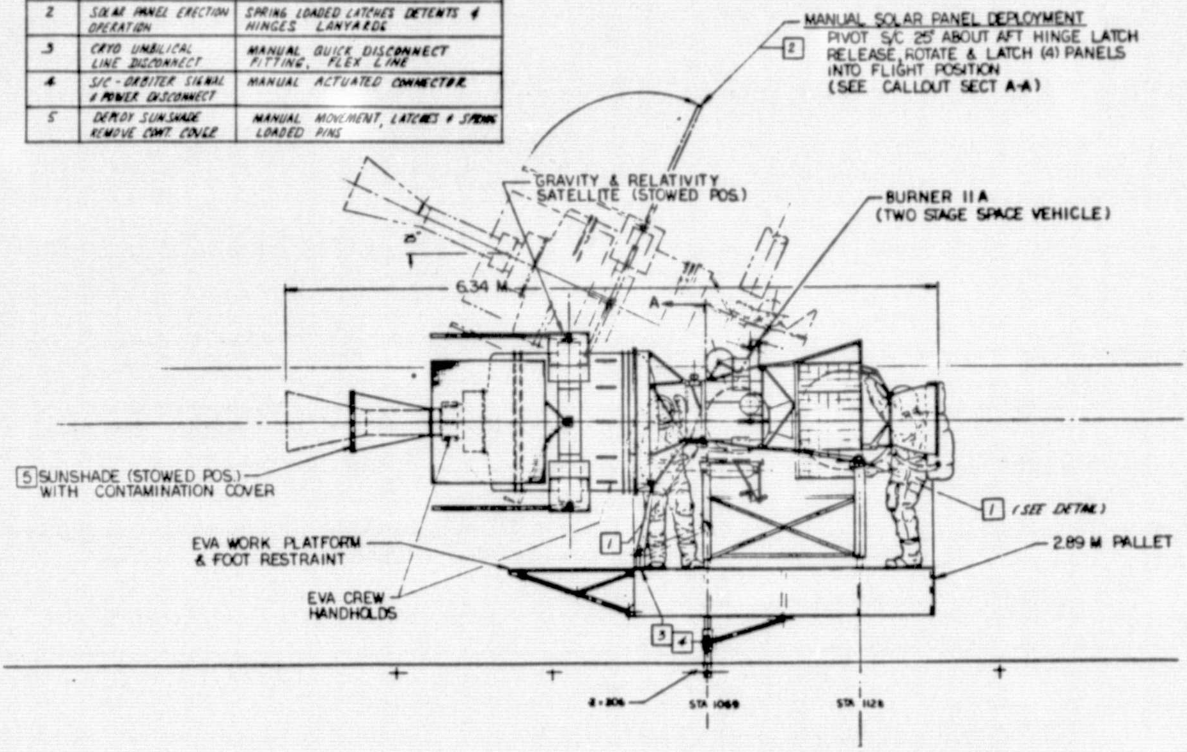


Figure 3-8. GRS Payload EVA Operations

sequence of blocks 10.1 through 10.11, excluding 10.6. If free-flight checkout should uncover GRS anomalies, the spacecraft could be recovered and repaired for subsequent launch or prepared for unscheduled return if desired systems checkout is not obtained. Since no recovery (other than above-mentioned contingency) is planned, the orbiter post-landing operations involve only return of the GRS support equipment to the integration center for reuse for a later delivery or modification for support of another payload. GRS also does not have planned maintenance operations.

Sequence Comparisons

The on-orbit operations sequence comparison for the GRS delivery missions is shown in Table 3-4. Most of the required operations functions refer to the basic sequences described earlier. The major variations from the basic were estimated to occur in sequences 1.3 ERECT SOLAR ARRAY and 1.4 OPERATE DEPLOYMENT DEVICE. The suggested EVA-oriented design change for the GRS is to

Table 3-4.
GRAVITY AND RELATIVITY SATELLITE (GRS)
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
1. PRE-OPERATIONS			
1.1 REMOVE CONTAMINATION SHIELDS (Telescope, star tracker, earth horizon sensors (2))			
Basic sequences			
1.2 DISENGAGE APPENDAGE BOOST LOCKS (Solar panels, sunshade)			
Basic sequences		Solar panels stored in payload bay and installed by EVA (see 1.3)	
1.3.2 ERECT SOLAR ARRAY (Four panels)			
Activate solar array circuits	PSS control console	Proceed to payload, extend sunshade and remove contamination cover	Handholds, work platform
Provide visual display of activities	CCTV	Remove 3 solar panels from storage	Payload bay storage
Activate mechanisms to erect 2 side and top solar arrays	Electromechanical rotation	Install top and two side solar panels on payload	Manual operation connectors on panel stems
Elevate payload assembly so bottom solar array clears orbiter	RMS	Engage RMS with payload	RMS control console
Operate solar array mechanism	Electromechanical rotation	Elevate and restrain payload to provide clearance for lower panel	RMS restraint rod connected to payload
Verify operation	PSS checkout console, event sensing microswitches	Install fourth solar panel	Manual operation panel
		Verify installation	On-site inspection, PSS checkout console
1.4 OPERATE DEPLOYMENT DEVICE			
Engage RMS with payload	RMS control console	Proceed to payload location	Handholds, work platform
Provide visual display of activities	CCTV	Release payload to support structure retention latches	Manual operating latches
Release payload to support structure retention latches	Electromechanical latches	Verify release	On-site inspection
Verify latch separation	Event sensing microswitches		
Power down circuits	RMS control console		
1.8 TEST, CHECKOUT (Instruments, subsystems)			
Basic sequences			
1.10 VISUAL INSPECTION (Pre-release inspection)			
Basic sequences			
1.11 REMOVE PYRO SHORTING PLUG			
Basic sequences			
1.13 POWER DEADFACE AND SWITCHOVER			
Basic sequences			
3. CONTINGENCY OPERATIONS			
See basic activity sequences for typical contingenc operations comparisons (Section 2)			

TABLE 3-4.

GRAVITY AND RELATIVITY SATELLITE (GRS)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
4. SEPARATE SPACECRAFT			
4.1 REMOVE UMBILICAL			
Basic sequences			
4.2 DISENGAGE SPACECRAFT			
Basic sequences			
4.3 TRANSFER TO SPACECRAFT GROUND			
Basic sequences			
5. DOCKING OPERATIONS (Contingency Operations Only)			
5.2 COCK BERTHING MECHANISM			
Basic sequences			
5.3 DIRECT PLACEMENT			
Basic sequences			
5.4 ENGAGE DOCKING LATCHES			
Basic sequences			
5.5 CONNECT UMBILICAL (Payload to orbiter)			
Basic sequences			
5.6 CONNECT TO SHUTTLE GROUND			
Basic sequences			
7. PREPARE FOR RETURN (Unplanned Operations)			
Prepare for return operations are generally the inverse of the similar named activities in section 1.0 Pre-Operations. In the contingency situation the liquid helium supply should be drained prior to return to the orbiter and vent attached to orbiter vent system.			

manually erect the four spacecraft solar array panels to their operating position. The payload will be partially rotated out of the orbiter payload bay and supported by the RMS in order to provide working clearance for the erection operations. Another EVA-oriented design will provide capability for manually extending and retracting the sensor sunshade. This would reduce the orbiter payload bay volume requirements for the GRS payloads.

Timeline Comparisons

Figure 3-9 compares timelines for automated (baseline) and the corresponding EVA-oriented procedure for completing the GRS delivery mission. The designated on-orbit checkout of the GRS spacecraft requires almost 10 hrs; therefore, the EVA operations require 2 separate periods. The baseline system operations required 11.2 hrs vs. 12.2 hrs for the EVA-oriented system. The corresponding comparison excluding the checkout time is 1.6 and 3.2 hrs. It was assumed that certain portions of the system checkout could be performed by the EVA crewman after his return into the pressurized area. About 8 hrs later the same or a different crewman would egress to complete the EVA activities. This would shorten the checkout period from 9.6 to 9.0 hrs.

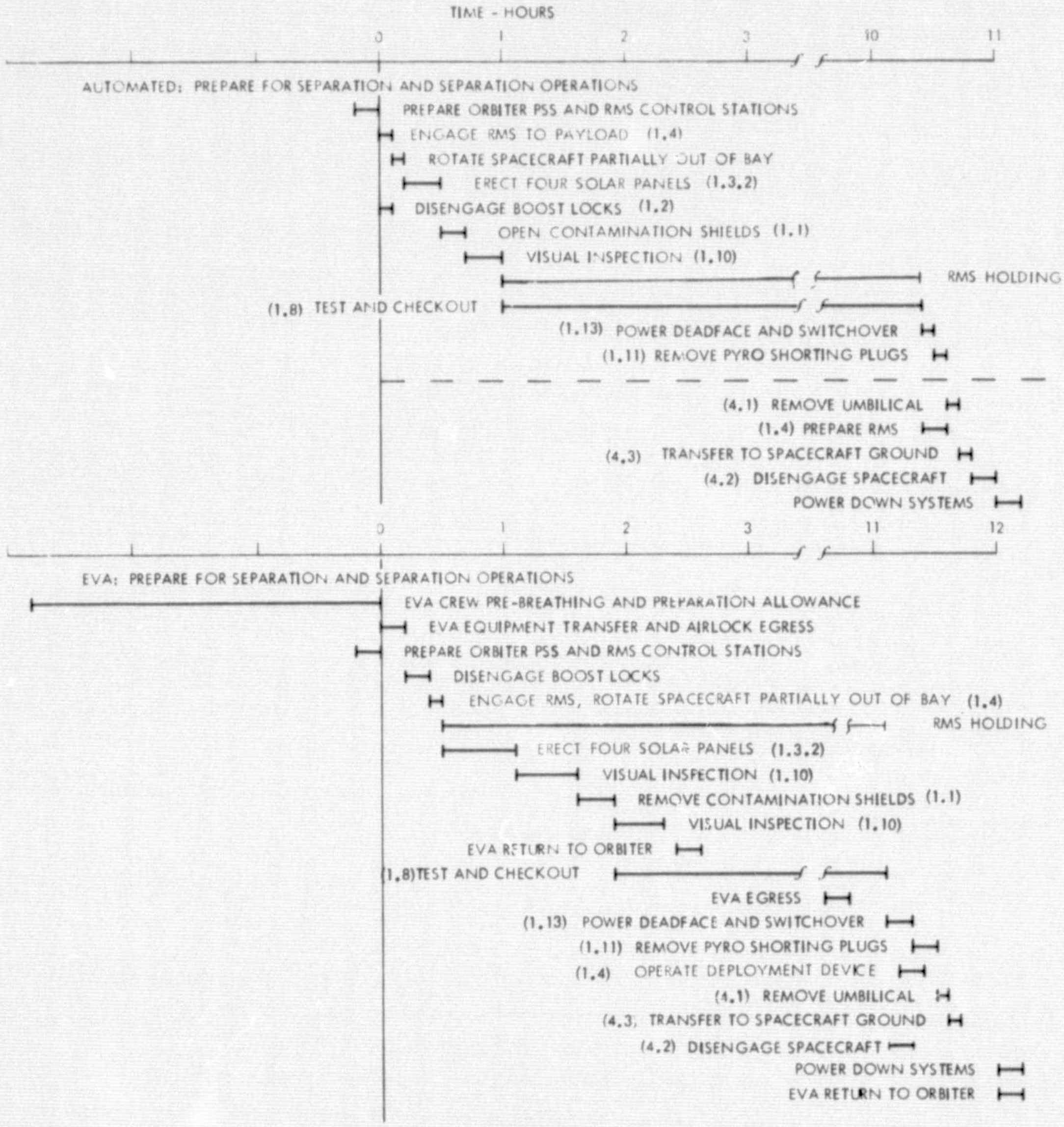
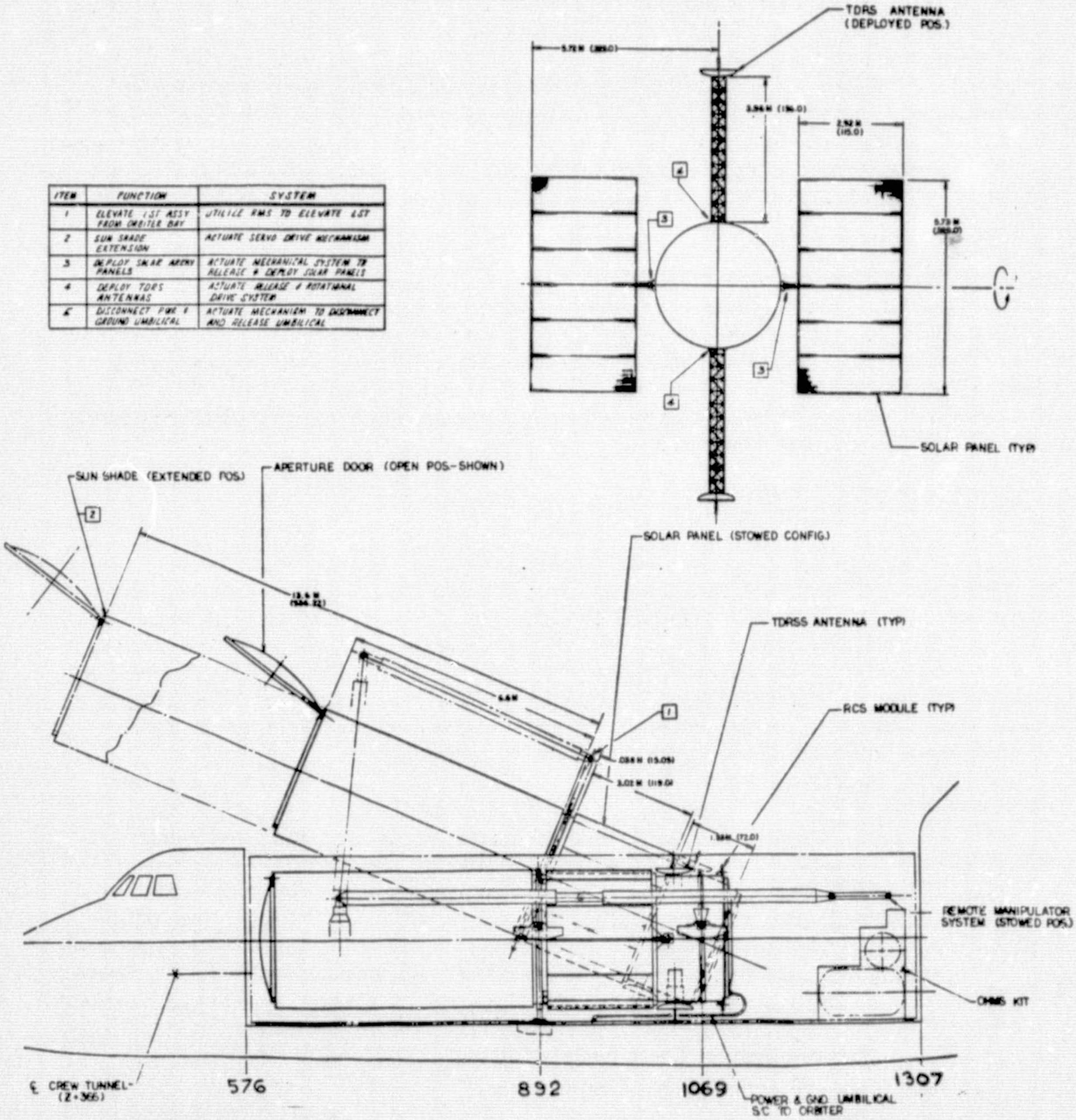


Figure 3-9. GRS - Preparation for Operation, Baseline and EVA Modes

3.4 LARGE SPACE TELESCOPE

Figure 3-10 illustrates the baseline Large Space Telescope (LST) installed in the Shuttle orbiter. Also indicated is the extension of the sunshade which can be accomplished only after the LST is partially rotated out of the orbiter payload bay. The LST is classified as a current design reusable payload with the design compatible with on-orbit servicing as well as retrieval and refurbishment on earth.



ITEM	FUNCTION	SYSTEM
1	ELEVATE LST ASSY FROM ORBITER BAY	UTILIZE RMS TO ELEVATE LST
2	SUN SHADE EXTENSION	ACTUATE SERVO DRIVE MECHANISM
3	DEPLOY SOLAR ARRAY PANELS	ACTUATE MECHANICAL SYSTEM TO RELEASE & DEPLOY SOLAR PANELS
4	DEPLOY TDRS ANTENNAS	ACTUATE RELEASE & ROTATIONAL DRIVE SYSTEM
5	DISCONNECT PWR & GROUND UMBILICAL	ACTUATE MECHANISM TO DISCONNECT AND RELEASE UMBILICAL

Figure 3-10. Baseline LST Payload

The orbiter RMS is utilized to rotate the spacecraft out of the payload bay. Servo drive mechanisms are provided to drive the telescope sunshade to its extended position and provide for opening of the sunshade aperture door. A flexible power and ground umbilical between the spacecraft and orbiter is utilized in order to allow movement of the spacecraft prior to release from the orbiter. An automated umbilical release and reconnect device will be required. Automated deployment systems are provided for spacecraft solar panels and communication antennas. These will be actuated after the LST is deployed to the point of clearing the orbiter structure. The details of the payload sensors and arrangement are shown in LST Phase A[1] and current study reports.

It is planned that a single instrument can be utilized during the 1980-1991 time period by use of periodic on-orbit servicing and less frequently, return to earth for refurbishment. The study schedule calls for telescope delivery to 28.5 deg inclination, 520 km orbit in 1982. Retrieval, earth-based refurbishment, and redelivery are scheduled for 1983, 1985, and 1988. Yearly on-orbit servicing missions are indicated for all the intervening years of the decade.

The object of the LST program is to utilize the large high quality telescope and a variety of complementary instruments to provide astronomical observations that are not possible with ground based telescopes. Observations in the ultraviolet and infrared regions of the spectrum will be emphasized. The specific observational program for the LST is still being planned and will be coordinated with the ground programs to provide anwers to the most pressing questions of the astronomy discipline.

3.4.1 Baseline Payload Operations

Delivery Missions

The automated routine of payload activation for the LST will start with preparation of the PSS and RMS control consoles for the early operations. A visual inspection of the payload will be made using the orbiter CCTV systems. The LST boost locks will be released and the spacecraft rotated approximately 25 degrees in order to allow extension of the telescope sunshade (see Figure 3-10). At this time the solar arrays and communication antennas will be deployed and test and checkout of subsystems started.

The complexity of the telescope and its instrumentation requires an extensive checkout time interval prior to release of the payload from the orbiter. A 48-hour quiescent period prior to opening the telescope cover is recommended. This will allow contamination clearing and the establishment of thermal equilibrium in the telescope structure. After cover opening another period of LST operations checks will be performed. After satisfactory completion of the checkout procedure, the LST separation operations will be performed and the orbiter translated away from the spacecraft. A free-flight checkout of the LST will be performed before the Shuttle orbiter returns to earth. If payload anomalies are discovered at this point, the LST will be recovered and repaired or returned to earth if necessary.

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(1) Large Space Telescope Phase A Final Report, Vol. II, Mission Description and System Design Characteristics, NASA TMX-64726, MSFC, December 1972.

Servicing Missions

LST design concepts have included the use of a modular subsystem and component arrangement with provisions for manual servicing. Special module exchange mechanisms, possibly activated through the RMS system, would be a requirement for automated servicing and exchange of components in the scientific instrument package and the support systems module of the LST, though such systems are not required by the current baseline concept.

The automated routine of LST capture and docking begin with the preparation of the PSS and RMS control station for the required operations. The RMS will be attached to the LST and then maneuver the LST to position for attachment to the orbiter. The Shuttle support umbilical is automatically connected to the spacecraft. The sunshade cover is closed and the sunshade retracted. Next, the solar panels and communication antennas are retracted. Protective covers will be closed and required safety items installed.

The modules requiring exchange during the servicing mission are assumed to have been determined by LST operations housekeeping, data output and long-range maintenance plans. Required modules are stored in the payload bay, probably in the vicinity of the orbiter OMS tanks. For study purposes it was assumed that 10 modules would be exchanged on a given servicing mission with an average time of one half hour per operation.

After completion of the maintenance module exchanges, other tasks such as sensor cleaning, and servicing of fluid system may be performed as required. Test and checkout of the installed modules will be accomplished and then the pre-separation tasks completed. Detailed checkout of the LST operations, similar to that of the previously described delivery mission, was not assumed for the servicing flight.

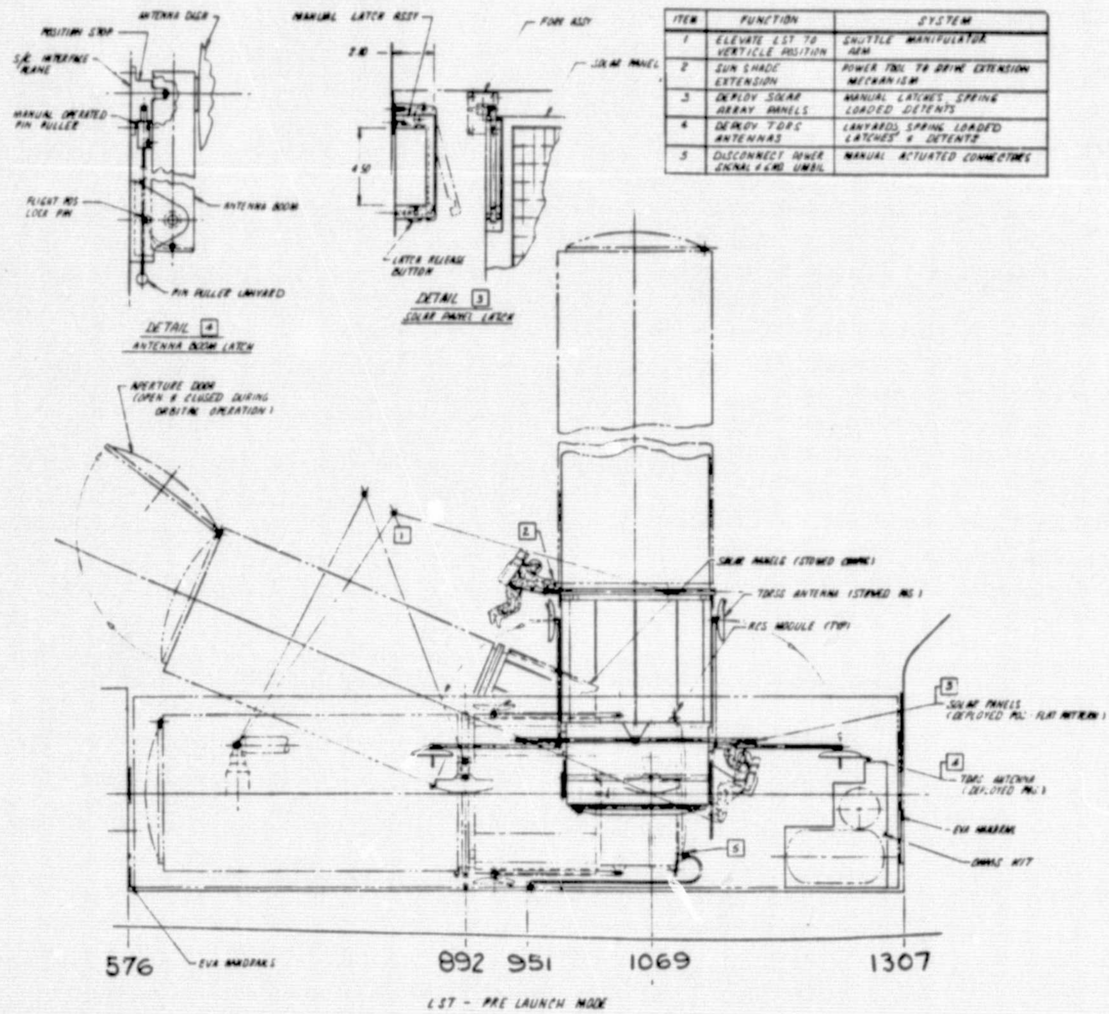
Retrieval Missions

The LST study schedules calls for a first retrieval and ground refurbishment of the spacecraft after one year of on-orbit operations and a second refurbishment after an additional 1-3 years of on-orbit operations.

Capture and docking operations will be identical to the same activity of the servicing mission. Preparation for returns will include automatic retraction of the LST sunshield, closing of the sunshield cover, retraction of solar panels, and retraction of the communication antennas. The previous activities must be completed before the LST can be rotated completely into the payload bay. After rotation into the bay, the entry latches will be fastened and safety items installed.

3.4.2 EVA Applications

EVA can eliminate certain of the automated devices for deployment and retraction of spacecraft equipment. The discussion of the EVA concepts for payload delivery, payload servicing, and payload retrieval missions for the LST are given below. Several EVA applications are illustrated in Figure 3-11.



ITEM	FUNCTION	SYSTEM
1	ELEVATE LST TO VERTICLE POSITION	SHUTTLE MANIPULATOR ARM
2	SUN SHADE EXTENSION	POWER TOOL TO DRIVE EXTENSION MECHANISM
3	DEPLOY SOLAR ARRAY PANELS	MANUAL LATCHES SPRING LOADED DETENTS
4	DEPLOY TDRS ANTENNAS	LANYARDS SPRING LOADED LATCHES & DETENTS
5	DISCONNECT POWER SIGNAL & GND UMBIL	MANUAL ACTUATED CONNECTORS

Figure 3-11. LST EVA Operations

Delivery Missions

Boost latch release for the LST remains an automated operation because of the lack of space in the orbiter payload bay for EVA until the LST is rotated out of the bay. For EVA operations it appears that the LST should be rotated 90 degrees out of the payload bay as shown in Figure 3-11.

Major EVA activities identified for preparation of the LST for separation include sunshade extension, deployment of solar arrays, deployment of communications antennas, and disconnection of the orbiter-to-payload umbilical. EVA

operations also include items such as release of the boost locks of the extended devices and inspection of the spacecraft prior to deployment. Opening of the sunshade cover probably will be maintained as an automated function in order to minimize the contamination problems for the LST optical surfaces.

The long duration test and checkout operations for the LST are performed in the automated mode. The EVA crew egresses again after checkout tests are completed to assist in the umbilical removal and final separation operations.

Servicing Missions

EVA operations are utilized for retraction of extended devices to the extent necessary prior to EVA servicing. EVA is also used to connect the orbiter-to-spacecraft umbilical, inspection of spacecraft, installation of safety items, and access of the spacecraft spares. For developing comparative data, it was assumed that a potential servicing mission will require the interchange of ten LST instrument or subsystem components. Performing these activities by EVA (the current LST program approach) requires two crew members in space suits, with an average of one hour per interchange. Figure 3-12 illustrates EVA maintenance of the LST.

Retrieval Missions

The EVA-oriented retrieval mission operations for the LST are similar to the servicing mission operations described above relative to rendezvous, capture, and docking with the spacecraft. Instead of the servicing operations, the LST will be prepared for entry. EVA activities include securing extended devices, inspection of the spacecraft, and attachment of the orbiter-to-spacecraft umbilical. These activities will be accomplished prior to rotating the LST entirely within the orbiter payload bay.

Final activities of subsystems checkout and preparation for entry will be performed in the automated mode.

3.4.3 Operations Analysis

Operations Cycle

The LST operations cycles are summarized in the block diagram of Figure 3-1. The normal delivery mission operations will include blocks 1 through 11 (except block 10.6, contingency operations). The maintenance mission sequence will go from block 10.4 to block 10.14 and continue as indicated. Similarly, a retrieval mission will include blocks 10.1-4, 10.12, and 10.15-.19. Typical contingency blocks also are indicated on the diagram.

Sequence Comparisons

A comparison of the baseline automated activity sequence and the EVA activity sequence for the LST is summarized in Table 3-5. Most items on the list refer to the basic sequence comparison table. The unique activity compared in this section is that of extending the telescope sunshade, item 1.3 of the table.

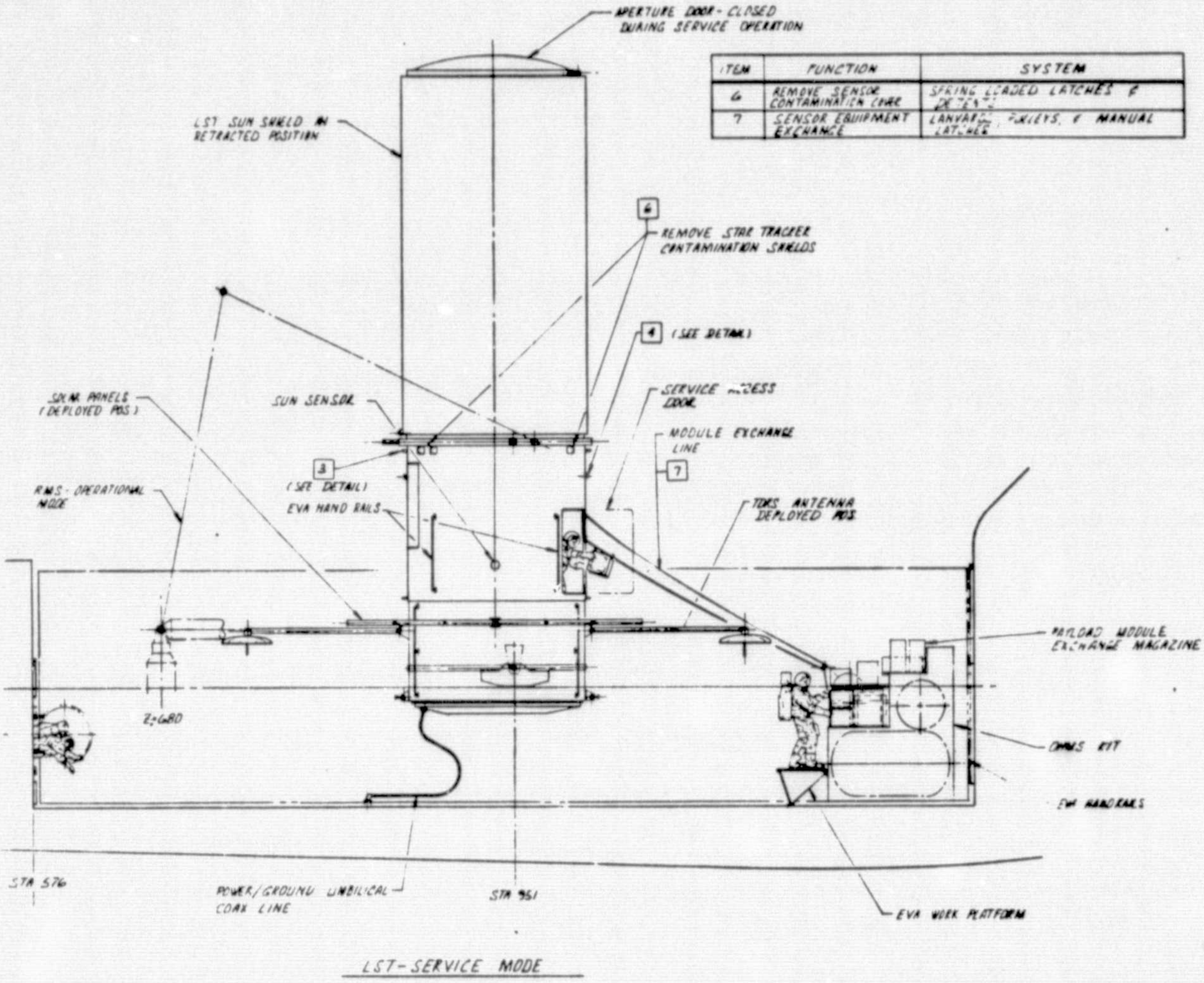


Figure 3-12. LST-EVA Maintenance Concept

Timeline Comparisons

Timelines were prepared for LST delivery missions and LST servicing missions. These are illustrated in Figures 3-13 and 3-14. LST operations were the longest in duration of all the representative payloads considered in this study. The long duration resulted primarily from the extensive on-orbit activation and checkout period required for the telescope. This, in turn, results in part from telescope sensitivity to contamination from the environment surrounding the Shuttle after maneuvering into the LST delivery orbit.

The total on-orbit period for the baseline LST operations is 133 hours; for the EVA-oriented system, 133.3 hours. With checkout time excluded, the times were 4.8 and 6.7 hours respectively.

Table 3-5.
LARGE SPACE TELESCOPE (LST)
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts	Sequence	Payload Functional Reqmts
1.1 REMOVE CONTAMINATION SHIELDS (Star trackers (2), sun sensor)			
Basic sequences			
1.2 DISENGAGE BOOST LOCKS (Solar panels (2), comm antennas (2))			
Basic sequences			
1.3.1 EXTEND ANTENNAS (2 communication antennas)			
Basic sequences			
1.3.3 EXTEND SUNSHADE			
Activate power circuits for sunshade extension mechanism and operations	PSS control console	Proceed to work station for sunshade extension operation	Handholds, work platforms
Provide visual display of operation	CCTV	Verify all clear	On-site inspection
Rotate telescope partly out of payload bay	RMS	Rotate telescope partly out of payload bay	RMS
Operate sunshade extension mechanism	Electromechanical extension system	Operate sunshade extension mechanism	EVA power tool
Verify extension complete	Event sensing microswitches	Verify extension complete, latch in extended position	Manual operated latches
Latch sunshade in extended position	Electromechanical latch	Power down circuits	PSS control console
Power down circuits	PSS control console		
1.8 TEST, CHECKOUT (Sensors and subsystems)			
Basic sequences			
1.10 VISUAL INSPECTION			
Basic sequences			
1.11 REMOVE PYRO SHORTING PLUGS			
Basic sequences			
1.13 POWER DEADFACE AND SWITCHOVER			
Basic sequences			
4. SEPARATE SPACECRAFT			
4.1 REMOVE UMBILICALS (Power and control)			
Basic sequences			
4.2 DISENGAGE SPACECRAFT			
Basic sequences			
4.3 TRANSFER TO SPACECRAFT GROUND			
Basic sequences			

Table 3-5. (continued)

LARGE SPACE TELESCOPE (LST)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	**Payload Functional Reqmts.**	**Sequence**	**Payload Functional Reqmts.**
5. DOCKING OPERATIONS			
Basic sequences			
6. PLANNED MAINTENANCE			
6.1 INSTALL PROTECTIVE COVERS (Star trackers)			
Activate power circuits for protective cover closure	PSS control console	Proceed to spacecraft locations	Handholds, tethers
Provide visual display of operation	CCTV	Remove covers from storage	Storage compartment
Operate protective cover mechanisms	Electromechanical cover rotation mechanisms	Place covers over sensors	Manual operation
Verify cover installation complete	Event sensing microswithces	Verify cover installation complete	Visual inspection
Power down cover installation circuits	PSS control console		
6.3 INSPECT SPACECRAFT			
Activate RMS and sensor	RMS control station	Proceed to spacecraft	Handholds, tethers, etc.
Provide visual display of spacecraft exterior	CCTV in payload bay and on RMS, light source	Inspect spacecraft for potential service & repair	On-site inspection, work platforms, light source
Inspect spacecraft exterior for anomalies	PSS display console	Report the potential repairs	Communication systems with PSS
Record observations of potential service and repair requirements	PSS		
Power down systems	PSS control console, RMS control station		
6.4 ACCESS SPACECRAFT AND SPARES (Components required for planned maintenance and changes planned per inspection)			
Activate RMS and maintenance end effector	RMS control station	Proceed to spares storage area	Handholds, tethers, etc.
Activate spares storage release mechanism circuits	PSS control station	Open storage cover and unlatch restraints on required replacement equipment	Hand-level mechanisms
Open spares storage container	Electromechanical latch, gear motor cover rotation device	Remove spacecraft access covers as required	Hand tools
Open spacecraft access covers as required	RMS and special end effectors		
Provide visual display of activities	CCTV in payload bay and on RMS		
6.5 REMOVE AND REPLACE			
Remove spacecraft module	RMS	Proceed to component storage area	Handholds, etcs.

Table 3-5. (continued)

LARGE SPACE TELESCOPE (LST)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
Transfer removed module to storage	RMS	Obtain new component	Manual operation
Transfer new module to spacecraft, insert	RMS	Remove old component, transfer, install new components, replace spacecraft cover	Manual operation, hand tools, equipment transfer unit
Repeat above steps as required	RMS	Repeat above steps as required	Hand tools
Check integrity of subsystems	PSS checkout console	Check integrity of subsystems	PSS checkout console
Replace spacecraft covers	RMS	Closeout access	Hand tools
Secure replaced modules in storage	Electromechanical latches	Store and secure all replaced parts	Hand latch mechanisms
6.7 CLEAN SENSORS			
Activate circuits	PSS control console	Proceed to work station	Handholds, etc.
Operate sensor cleaning technique (built-in devices)	Gas jets, mechanical cleaners	Clean sensors	Portable gas jet, lens brush, etc.
Power down circuits	PSS		
6.8 REPAIR MECHANICAL ITEMS (Items as required per inspection)			
Return spacecraft to ground		Remove malfunctioning item	Hand tools
		Transfer to pallet work station	Handholds
		Repair mechanical item	Work bench, hand tools
		Return item to spacecraft and install	Hand tools
		Check operations	PSS control console, on-site inspection
6.9 SERVICE FLUID SYSTEM (Cold gas, RCS)			
Engage RMS to tank	RMS control console	Same	
Release tank retention latches & disconnect	PSS control console, end effector	Release tank retention latches & break disconnect	Manual operating latches, manual quick disconnect
Remove tank from payload, move to storage	RMS	Remove tank from payload, move to storage	RMS, manual latches
Transfer new tank from storage to payload	RMS	Transfer new tank from storage to payload	RMS
Fasten tank to payload, deactivate connector	RMS, end effector	Secure tank to payload, engage connector	Manual operating latches, manual valve
Verify system	PSS checkout console	Verify system	PSS checkout console, on-site inspection

7. PREPARE FOR RETURN

Prepare for return operations are generally the inverse of the similar normal activities in Section 1.0 Pre-Operations.

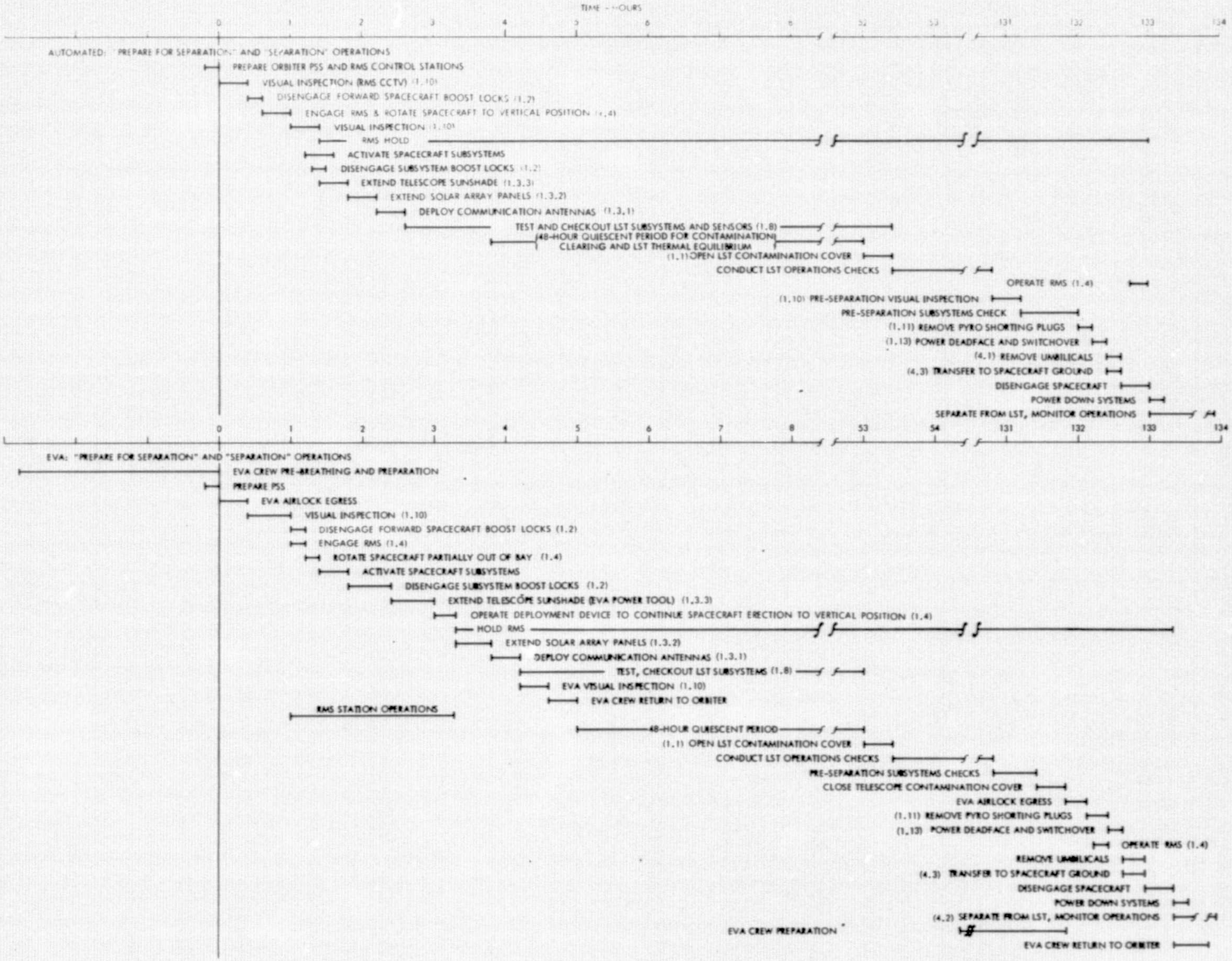


Figure 3-13. LST - Preparation for Operation, Baseline and EVA Modes

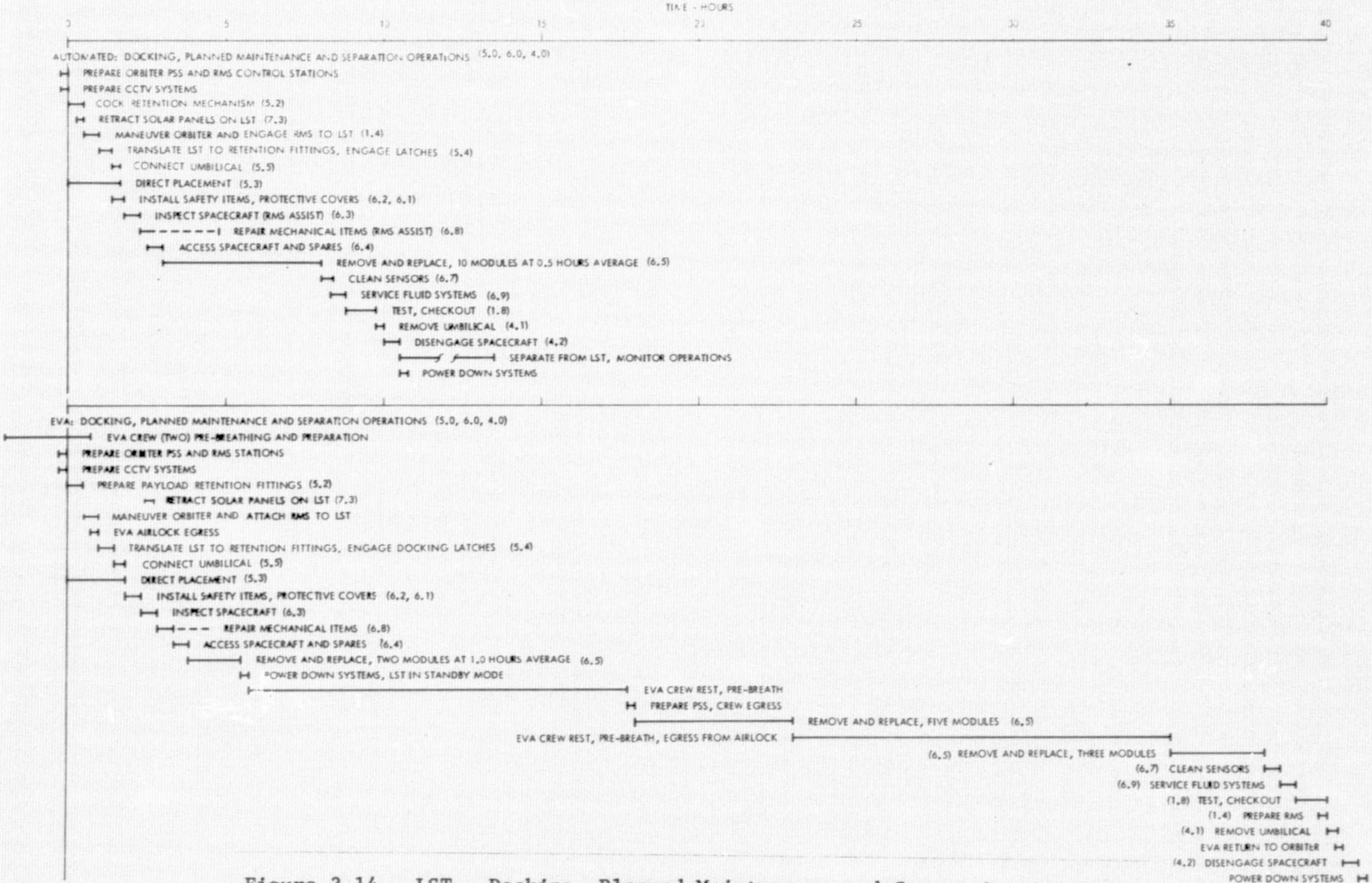


Figure 3-14. LST - Docking, Planned Maintenance and Separation Operation
Baseline and EVA Modes

For the LST maintenance missions, only minor checkouts were scheduled after the remove and replace operations were completed. The baseline on-orbit operations were then estimated to require approximately 10.5 hours. The EVA operations cycle for the maintenance mission was complicated by the limitation of approximately 6 hours for an EVA duration, a longer module replacement cycle, and the ground rule of a 12-hour interval prior to a second EVA egress. The total timelines for this case came to approximately 41 hours.

3.5 MINILAGEOS

Figure 3-15 illustrates the baseline concept of an assembly of two MiniLAGEOS Satellites (MIN) mounted on a structural frame and provided with a contamination protection enclosure. The spacecraft is a relatively simple, dense, and passive 0.5 meter diameter spherical structure uniformly covered with laser corner reflectors.

4	RETRACT SATELLITE CONTAMINATION COVER	ACTUATE SERVO MECHANISM TO RETRACT PAYLOAD CONTAMINATION SHIELD
5	RELEASE SATELLITES TO ORBIT	SERVO RELEASE OF EJECTION SYSTEM FOR PAYLOAD SATELLITES

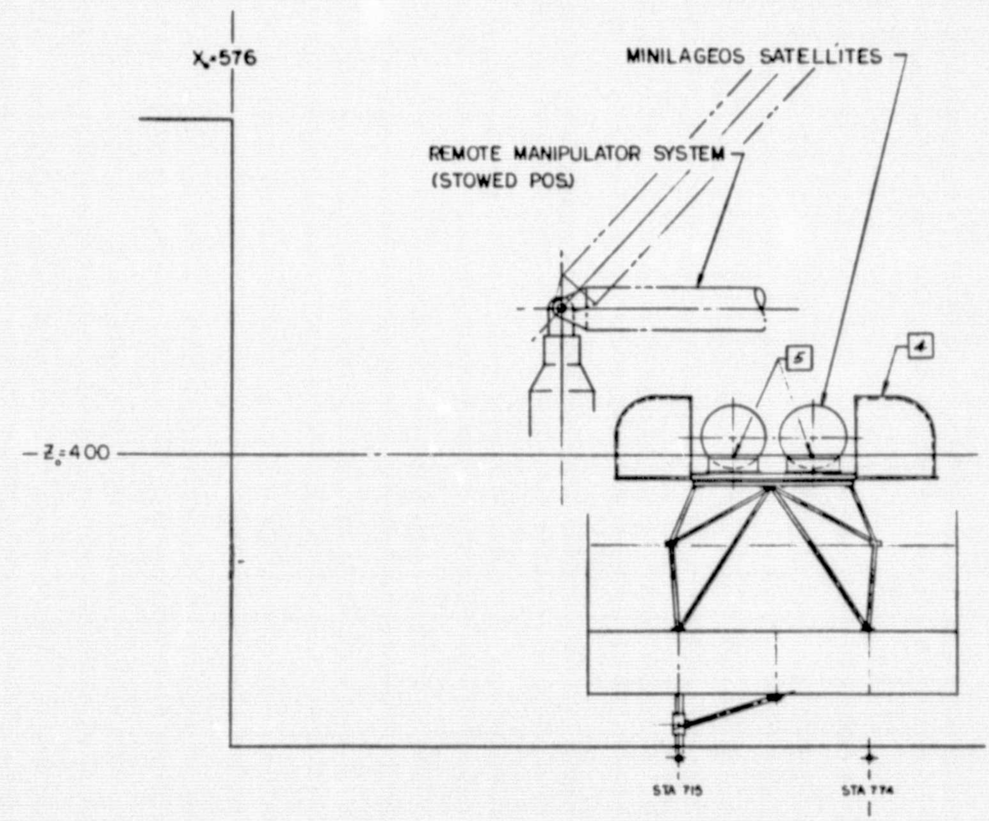


Figure 3-15. Baseline Minilageos Payload

The MiniLAGEOS program calls for two spacecraft to be launched in the same general orbit but with a low relative separation velccity. The proposed support equipment design calls for an automated ejection mechanism to provide approximately one foot per second velocity relative to the orbiter, then repeating the same operation for the second satellite after rotating the orbiter 180 degrees. This will then provide the desired separation velocity.

The protective cover also is opened by an automated mechanism. The structural frame is mounted on a section of the payload bay pallet in an area where interference with other orbiter payloads will be at a minimum. The current program plan indicates the launching of three pairs of the satellites in three different orbits, with launchings scheduled through 1985. The desired orbits are approximately 28.5 degrees, 55 degrees, and 90 degress. The desired altitude has been given as 650 km. However, the MIN payload will be only a small portion of a Shuttle cargo so other payload requirements may become the governing factor in orbit characteristics selection.

3.5.1 Baseline Payload Operations Definition

The automated routine of the MIN "prepare for separation" and "separation" operations begins with activation of the PSS control station and checkout of the automated contamination cover and deployment mechanisms. The contamination cover removal mechanism is activated to uncover the spacecraft. The orbiter is maneuvered to the desired attitude for ejection of the spacecraft. The automated release mechanism is activated to impart a separation velocity of 1 or more fps between the orbiter and spacecraft. The automated operations for MIN can then be completed by closing and latching the contamination covers and performing the control station power-down operations.

3.5.2 EVA Applications

The EVA-oriented operations for MIN delivery substitute manual activation for mechanized operations of supporting systems. The contamination cover release is manually actuated to eliminate the automated mechanism. Similarly, the ejection of the MIN's from the orbiter is manually activated, and the contamination cover is manually closed and latched in preparation for the orbiter return. A sketch illustrating EVA activity for MIN is shown in Figure 3-16.

3.5.3 Operations Analysis

Operations Cycle

The relatively simple operations cycle for the MiniLAGEOS is illustrated in Figure 3-1. Since the spacecraft are entirely passive, the possibility of malfunction during the operations is virtually eliminated and would essentially terminate at block 10.7. The spacecraft do, however, require care in handling during all phases, and protection from contamination of the reflective surfaces until successfully launched. The "prepare for separation" operations involve only the on-board launching mechanisms.

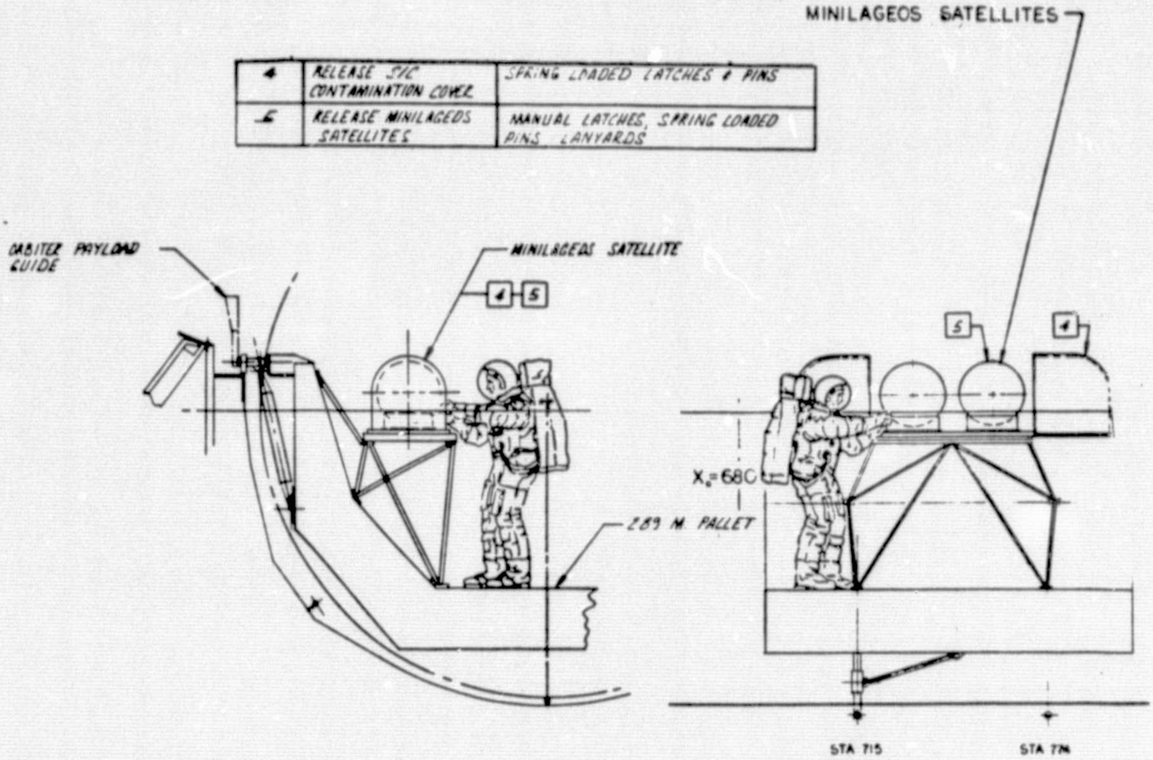


Figure 3-16. MiniLAGEOS EVA Operations

Sequence Comparisons

The on-orbit operation sequence comparison for the MiniLAGEOS delivery mission is shown in Table 3-6. For this spacecraft the operations are limited to the removal of the spacecraft contamination shield and disengagement of the spacecraft. The use of EVA will simplify the design requirements for these two functions.

Timeline Comparisons

The time estimate to accomplish the on-orbit operations for the delivery of two MiniLAGEOS spacecraft is shown in Figure 3-17 for both the baseline and EVA systems. The estimate for the automated system was 1.5 hours and for the EVA system 1.7 hours to the point of release and observation of release of the second spacecraft. EVA close-out and system power down time estimates subsequent to release also are shown.

Table 3-6.

MINILAGEOS (MIN)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload functional Reqmts.
1. PRE-OPERATIONS			
1.1 REMOVE CONTAMINATION SHIELD			
Activate circuits	PSS control console	Proceed to payload location	Handholds
Operate payload cover release mechanism	Electromechanical cover withdrawal mechanism	Remove payload covers	Manual operating cover removal mechanism
Verify release complete	Event sensing microswitch, CCTV and display	Verify completion	On-site inspection
Power down circuits			
1.10 VISUAL INSPECTION			
Completed in sequence 1.1			
4. SEPARATE SPACECRAFT			
4.2 DISENGAGE SPACECRAFT			
Activate circuits	PSS control station	Orbiter orientation for release attitude	EVA work station, orbiter control
Provide visual display of operations	CCTV	Release payload 1	Manual operating release latch, mechanism to transmit ~1 fps separation velocity
Orient orbiter for proper payload release attitude	Orbiter control	Observe payload separation	PSS, EVA
Release payload 1 attachment	Electromechanical latch release, mechanism to transmit ~1 fps separation velocity	Orbiter orientation for payload 2 release attitude	Orbiter control
Observe payload separation	PSS	Release payload 2	Manual operating release latch, mechanism to transmit ~1 fps separation velocity
Orient orbiter for proper attitude to release payload 2	Orbiter control	Close payload contamination	Manual operating mechanism
Release payload 2	Electromechanical latch release, mechanism to transmit ~1 fps separation velocity		
Close payload contamination covers	Operating mechanism		
Power down circuits	PSS control console		

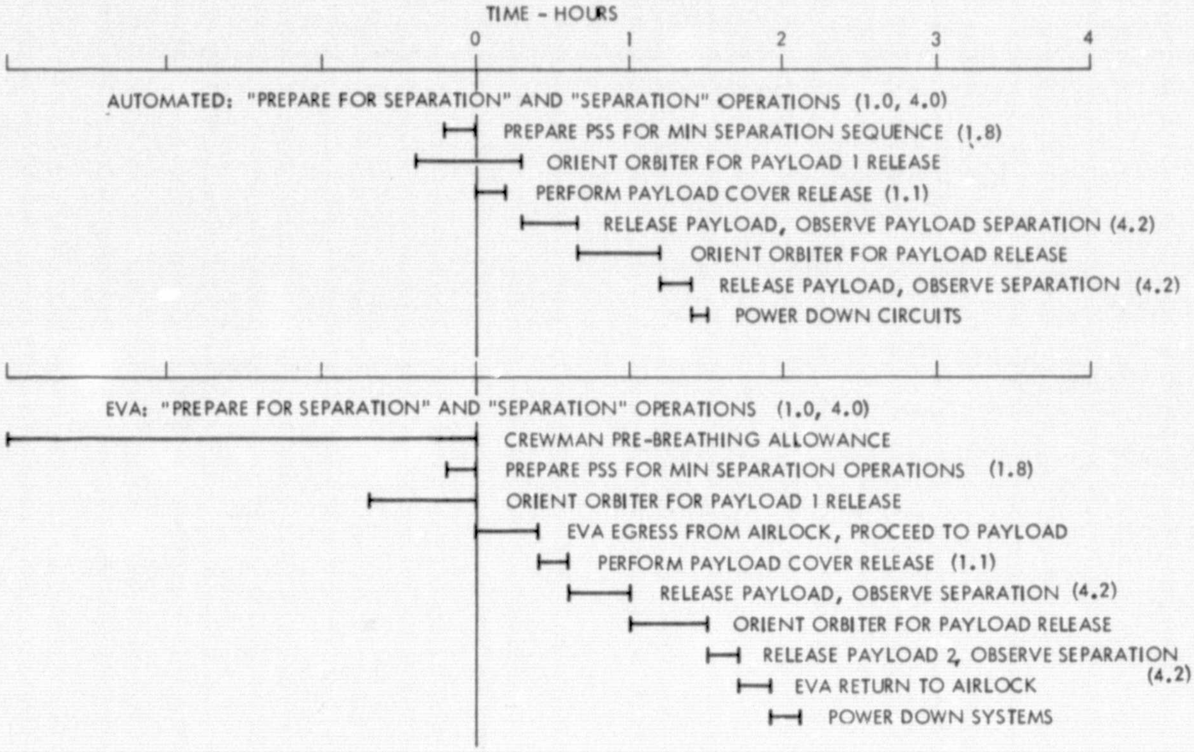


Figure 3-17. MIN - Preparation for Operation, Baseline and EVA Modes

3.6 MAGNETIC FIELD MONITOR

The Magnetic Field Monitor (MFM) representative payload is a low-cost, reusable payload. The baseline design is illustrated in Figure 3-18, where it is shown attached to a Burner II stage that provides transfer from orbiter altitude to the spacecraft operational altitude.

ITEM	FUNCTION	SYSTEM
1	SOLAR PANEL ERECTION	ELECTRICAL DRIVE MOTOR FOR S/P ERECTION, SELF LOCKING DETENT
2	SOLAR PANEL BOOST LOAD PIN PULLER	ELECTRO MECHANICAL SERVO ACTUATED PIN PULLER
3	PAYLOAD BOOST & RELEASE	ELECTRO MECHANICAL SERVO ACTUATED OVERCENTER LATCH
4	SIGNAL POWER & GROUND LINE DISCONNECT	SERVO ACTUATED UMBILICAL DISCONNECT

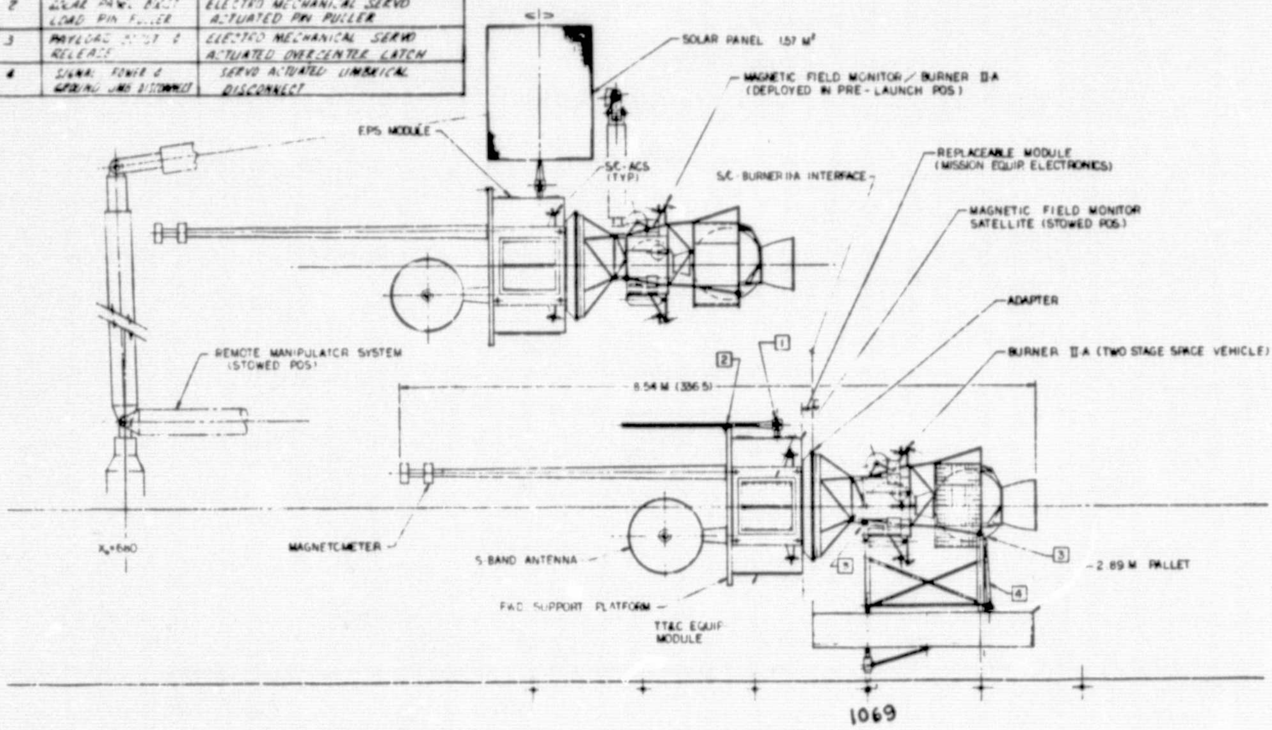


Figure 3-18. Baseline MFM Payload

The mission equipment for the payload consists of a vector magnetometer and a scalar magnetometer together with their supporting electronics. The magnetometers are mounted at the end of a 4.4-meter boom. A fixed S-band antenna and a single solar panel are externally mounted to support modules. The solar panel is shown in the stowed position. A solar panel automated erection mechanism and an automated boost latch-release mechanism are indicated on the figure. Also shown are the location of electromechanically activated boost latches holding the upper stage on the mounting frame, and a servoactuated umbilical disconnect for the signal, power, and spacecraft-to-orbiter ground connections. A nitrogen gas system provides backup attitude control and momentum dumping for the three-axis momentum wheel attitude control system.

The Magnetic Field Monitor spacecraft objective is to monitor the earth's magnetic field at a medium altitude. An orbit inclination of 28 degrees and an altitude of 1500 km has been specified for spacecraft operations. Delivery missions are scheduled for 1982 and 1986. Retrieval missions are scheduled for 1984 and 1987. The spacecraft has had a design lifetime of one year.

Since the MFM operational altitude is beyond the normal operating range of the Shuttle, the Burner II stage is used to provide the added energy required for attaining the spacecraft operational altitude. The maximum thrusting load was estimated at approximately 1.8 g.

3.6.1 Baseline Payload Operations Definition

The routine of the MFM payload activation and checkout beings with preparation of the PSS and RMS control centers for automated operations. The solar array boost locks are removed by operation of the electromechanical actuators. The solar array is next erected to its operating position and the array mechanisms and other spacecraft operations tested. Visual inspection of the payload is completed by use of the orbiter CCTV subsystems. The RMS is then attached to the MFM and the payload/upper stage boost locks released.

The power deadface and switchover mechanism is activated and the pyro shorting plug is removed. The orbiter-to-payload umbilical is released; this action also serves to perform the "transfer to spacecraft ground" function. The RMS then translates the MFM to the release position where the RMS end effector is disengaged.

The PSS crew next monitors the free-flight checkout of the spacecraft/ upper stage and the departure to the MFM operational orbit.

Retrieval Missions

It is assumed the MFM retrieval missions will be accomplished with the assistance of the space tug planned for the time period of the retrieval. The MFM/tug capture and docking operations for the automated mode will be directed from the orbiter or ground control centers. These will be primarily Tug operations which are not analyzed in this study. The "prepare for return" operations for the MFM, itself, will require automated retraction of the appendage boost locks. Safety items will be installed. After orbiter landing the MFM will be transported to a refurbishment facility to be prepared for a subsequent flight.

3.6.2 EVA Applications

The EVA-oriented concept of MFM payload operations shown in Figure 3-19 illustrates possible variations of payload design which may be more practical with EVA operations than with the automated mode. For example, the spacecraft boom on which the two magnetometers are mounted extends approximately 4.4 meters beyond the main body of the spacecraft. The solar panel in the stored position and the S-band antenna likewise extend forward of the main body. In the EVA concept, the magnetometer boom and the solar panel assemblies are stowed in the orbiter payload bay separate from the spacecraft main structure and are

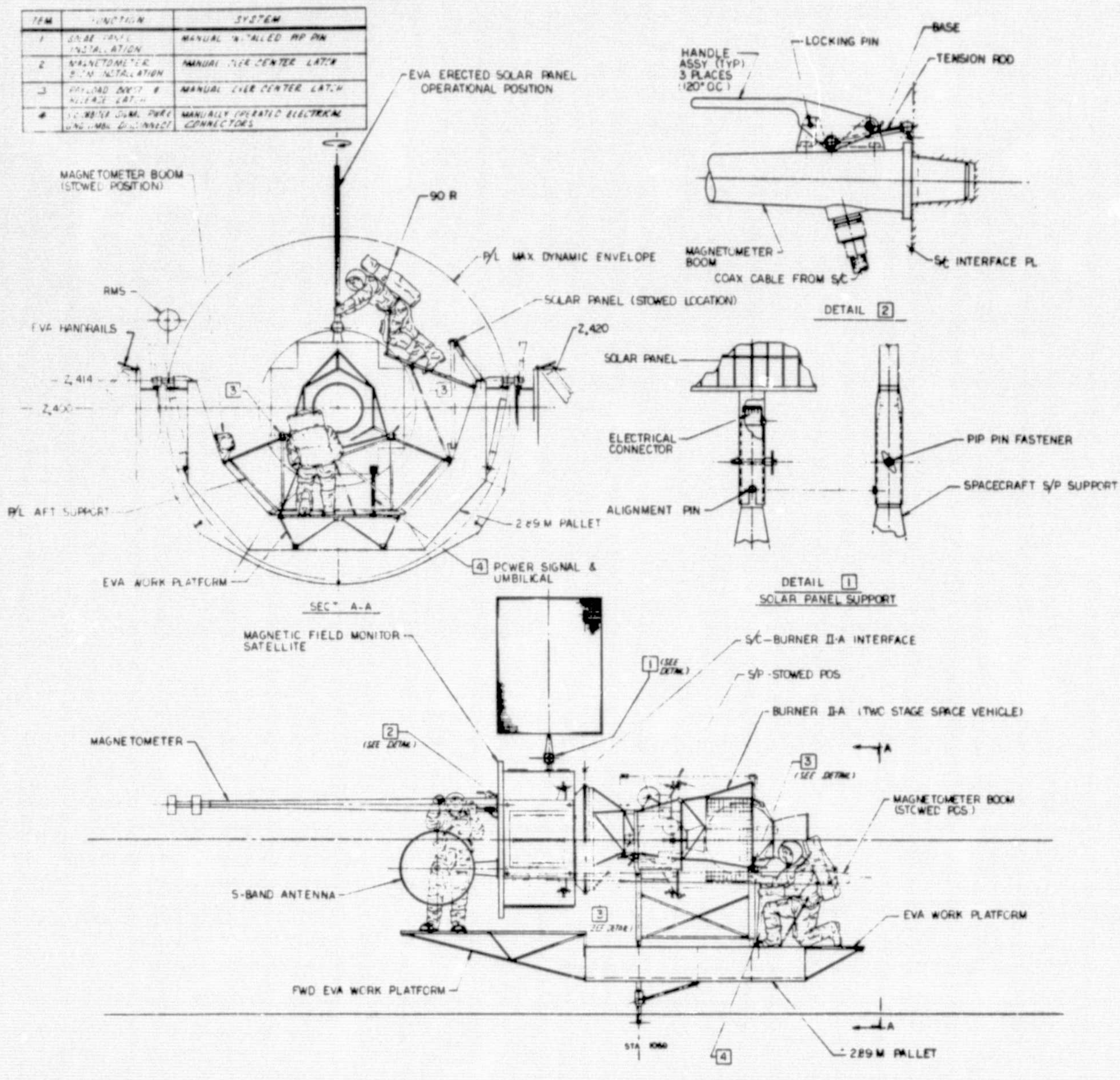


Figure 3-19. MFM Payload EVA Operations

assembled manually on-orbit. This saves orbiter bay length of approximately 2.5 meters which would be available for other payload installations and eliminates the requirement for the panel erection mechanism.

EVA also substitutes for automated mechanisms to perform operations such as connecting or disconnecting power deadface and switchover circuits, installing or removing pyro shorting plugs, releasing or fastening boost locks, removing or replacing contamination covers and releasing or connecting the

orbiter to spacecraft umbilical. EVA also is used in spacecraft inspection operations and in directing retrieval and placement of the spacecraft into the orbiter payload bay.

3.6.3 Operations Analysis

Operations Cycle

The operations cycle block diagram for the MFM is indicated in Figure 3-1. The normal delivery mission is indicated in blocks 10.1 through 10.11 excluding 10.6. The retrieval mission cycle would utilize blocks 10.1-10.4, 10.12,10.15-10.19. Blocks 10.13 and 10.14, servicing and maintenance operations, would not be a regularly planned function for the MFM--ground refurbishment being the preferred servicing mode.

Sequence Comparisons

Table 3-7 lists the activity sequences for the MFM delivery mission. The selected sequences were all related to the basic sequences which should be consulted to make comparisons between the automated and EVA systems.

Timeline Comparisons

Timeline comparisons for the on-orbit operations for the MFM delivery missions are illustrated in Figure 3-20. The total times to spacecraft release are 2.4 hours for the automated and 3.5 hours for the EVA assisted activities. the corresponding times with the automated test and checkout interval excluded were 1.4 and 2.3 hours.

Table 3-7.
MAGNETIC FIELD MONITOR (MFM)
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
1.1 REMOVE CONTAMINATION SHIELDS (Earth sensors, sun sensors, star sensors)			
Basic sequences			
1.2 DISENGAGE APPENDAGE BOOST LOCKS (Solar panel, antenna dish)			
Basic sequences			
1.3.2 ERECT SOLAR ARRAYS (Solar panel)			
Basic sequences			
1.3.3 ERECT INSTRUMENT BOOM (Magnetometer boom)			
Basic sequences			
1.7 INSTALL INSTRUMENTS (Vector magnetometer, scalar magnetometer)			
Basic sequences			
1.8 TEST, CHECKOUT (Instruments, subsystems)			
Basic sequences			
1.10 VISUAL INSPECTION (Pre-release inspection)			
Basic sequences			
1.11 REMOVE SHORTING PLUGS (IUS/spacecraft release system)			
Basic sequences			
1.13 POWER DEADFACE AND SWITCHOVER (Spacecraft)			
Basic sequences			
4. SEPARATE SPACECRAFT			
4.1 REMOVE UMBILICALS (Orbiter to spacecraft)			
Basic sequences			
4.3 TRANSFER TO SPACECRAFT GROUND			
Basic sequences			
5. DOCKING OPERATIONS			
Basic sequences			
7. PREPARE FOR RETURN (CONTINGENCY ONLY)			
7.1 INSTALL CONTAMINATION SHIELDS (Star tracker)			
Basic sequences			
7.2 ENGAGE ENTRY LATCHES (Spacecraft to IUS - 2 latches)			
Basic sequences			
7.3 REMOVE INSTRUMENTS			
Instruments remain mounted in automated mode		Proceed to work platform	Handholds, etc.
Inspect instruments for entry entry	CCTV in bay	Remove instruments if required	Hand tools, light
		Store instruments in orbiter bay	Instrument tie-downs

Table 3-7. (continued)

MAGNETIC FIELD MONITOR (MFM)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
7.4 ENGAGE RMS / OPERATE STOW DEVICE			
Activate RMS circuit	RMS control station	Proceed to work platform	Handholds, foot restraints
Attach RMS to payload	End effector, RMS control station	Observe RMS movement to attachment interface	Light source
Move spacecraft to final attach position	RMS control station	Close RMS end effector on payload attachment interface	Lever operated end effector
Provide visual display of final lineup	CCTV in payload bay	Guide movement of spacecraft	Light source
7.7 STOW/LOCK REMOVED COMPONENTS			
Basic sequences			
7.9 INSPECT FOR ENTRY			
Basic sequences			
7.10 INSTALL SHORTING PLUGS			
Basic sequences			
7.11 POWER DEADFACE AND SWITCHOVER			
Basic sequences			
7.12 DRAIN/PURGE FLUID SYSTEMS (Cold gas for attitude control)			
Basic sequences			

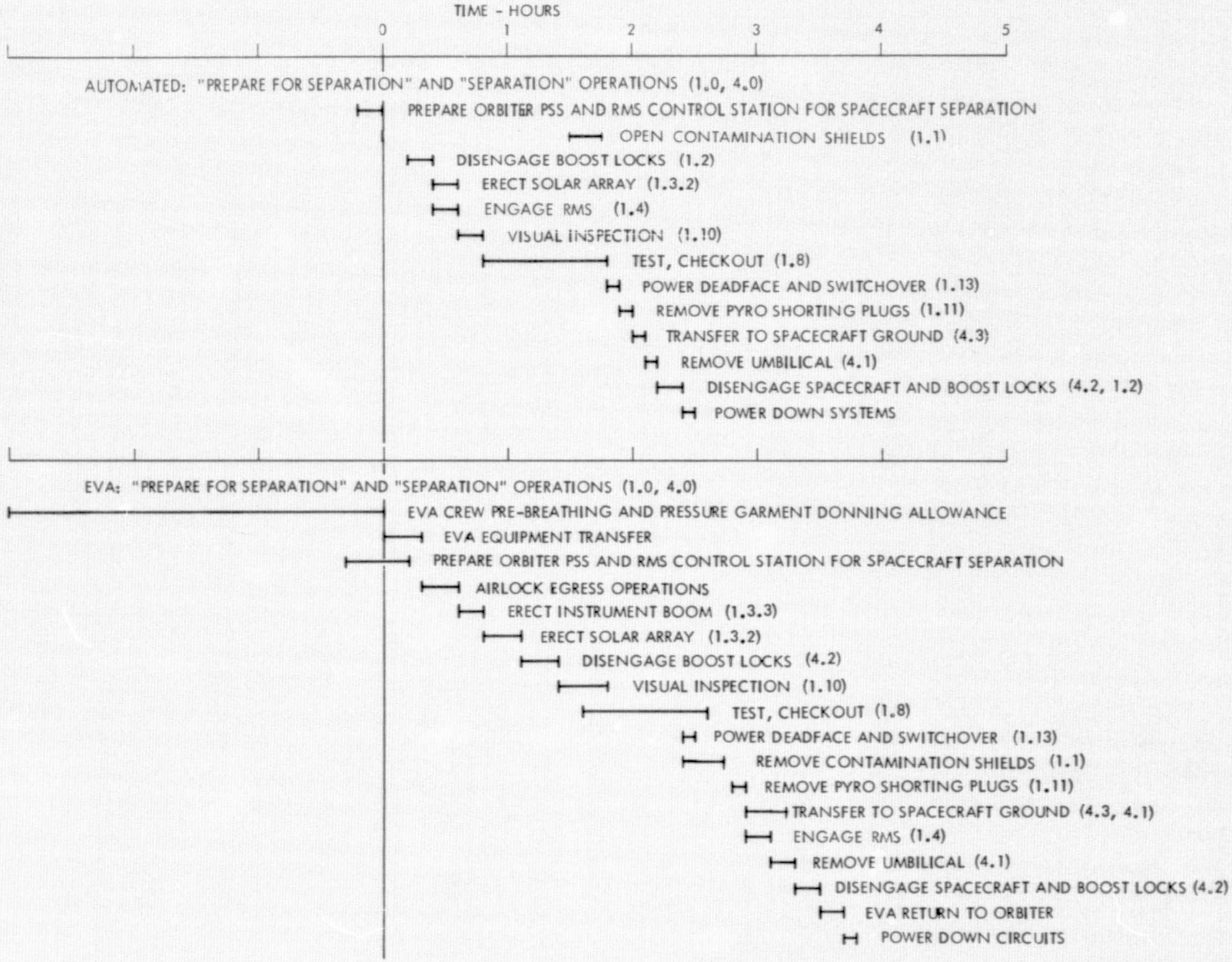
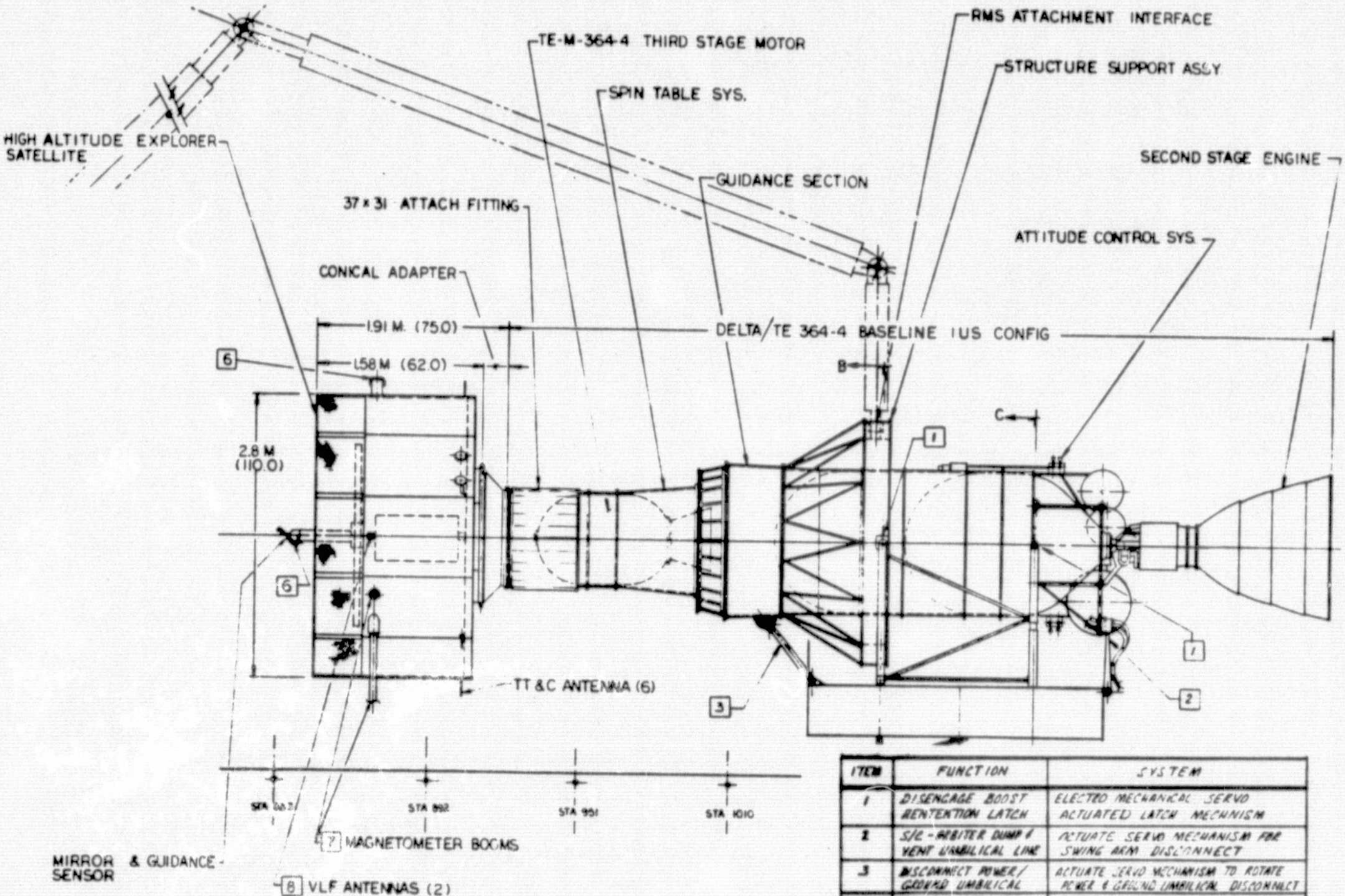


Figure 3-20. MFM - Preparation for Operation, Baseline and EVA Modes

3.7 HIGH ALTITUDE EXPLORER

The High Altitude Explorer (HAE) represents the class of low-cost expendable payloads requiring an upper stage (e.g., IUS) for placing the spacecraft into a higher energy orbit. Figure 3-21 depicts the baseline HAE payload assembly with a Delta/TE 364-4 IUS. Also shown is a spin table between the IUS and a third stage motor to which the payload is attached. The IUS is mounted on a special payload frame attached to a Spacelab pallet section.



ITEM	FUNCTION	SYSTEM
1	DISENGAGE BOOST RENTENTION LATCH	ELECTRO MECHANICAL SERVO ACTUATED LATCH MECHNISM
2	S/C - ARBITER DUMP & VENT UMBILICAL LINE	ACTUATE SERVO MECHANISM FOR SWING ARM DISCONNECT
3	DISCONNECT POWER/GROUND UMBILICAL	ACTUATE SERVO MECHANISM TO ROTATE POWER & GROUND UMBILICAL DISCONNECT
6	REMOVE SENSOR COVERS	ACTIVATE MECHANISM TO RELEASE SPRING LOADED CONTAMINATION COVERS
7	DEPLOY MAGNETOMETER BOOMS	ACTUATE DRIVE MECHANISM TO DEPLOY SENSOR BOOMS
8	EXTEND VLF ANTENNAS	ACTUATE ANTENNA EXTENSION & DEPLOYMENT MECHANISM

Figure 3-21. Baseline HAE Payload

The boost retention latches are electromechanically operated to separate the spacecraft after the RMS is attached to the payload. Also, electromechanically operated are the swing arm fluid dump and vent umbilical shown at the rear of the IUS, and the power, signal, and spacecraft ground umbilical shown forward of the IUS.

The mission equipment for the HAE payload includes two electric field detectors, two magnetometers, a high-energy particle spectrometer, a solar wind spectrometer, and a VLF receiver with antennas. TT&C antennas also are indicated on the figure. The VLF antennas and magnetometer booms are automatically extended after completion of the third stage boost phase and stabilization of the spacecraft. A series of five HAE delivery missions are planned, one delivery every other year starting in 1982 through 1988 plus one added delivery in 1989. Each spacecraft will be designed to operate for approximately one year after launching.

3.7.1 Baseline Payload Operations Definition

The automated routine of HAE activation and checkout will start with the preparation of the PS control station for the ensuing activities. The next planned operations include a visual check of the entire spacecraft using the orbiter CCTV followed by an extensive checkout (approximately eight hours) of the spacecraft and upper stage.

At the conclusion of the systems and subsystems checkout in the orbiter bay, the RMS will be attached to the assembly, the contamination shield removal mechanisms activated, pyro-shorting plug removal mechanism operated, and power deadface and switchover mechanism operated. The transfer to the spacecraft ground function will be accomplished together with the removal of the "spacecraft to orbiter" umbilicals. Magnetometer booms and VLF antennas are deployed after the spacecraft is moved out of the orbiter payload bay. The required upper stage "prepare for separation" functions also will be accomplished prior to the extension of the assembly by the RMS and separation of the orbiter from the payload.

3.7.2 EVA Applications

Some of the operations for which EVA can substitute for automated mechanisms are highlighted in Figure 3-22. Recommended EVA for the HAE includes the use of manually operated latches for payload boost latch release, manual operated disconnect of power and vent umbilicals, manual removal of contamination covers, and manual installation of sensor booms and antennas. EVA also is used for visual inspection of the payload and monitoring of mechanism checkout operations.

3.7.3 Operations Analysis

Operations Cycle

Figure 3-1 illustrates the major operations for the HAE delivery mission from delivery to spacecraft launch and Shuttle return. HAE support equipment mounted in the orbiter is returned to the HAE integration site for reuse on later missions. Contingency operations (Blocks 10.16 through 10.19) requiring return to earth for repair also are indicated in the event of contingencies.

ITEM	FUNCTION	SYSTEM
1	DISENGAGE PAYLOAD BOOST & RELEASE LATCH	MANUAL ACTUATED OVER CENTER LATCHS
2	S/C-ORBITER DUMP & VENT UMBILICAL ARM	MANUAL QUICK-DISCONNECT
3	S/C-ORBITER POWER/GROUND UMBILICAL	MANUALL OPERATED ELECTRICAL CONNECTORS

6	REMOVE SENSOR COVERS	MANUAL REMOVAL OF CONTAMINATION COVERS
7	MAGNETOMETER BOOMS ASSY	MANUAL ASSY & INSTALLATION OF SENSOR BOOMS
8	VLF ANTENNAS	ASSEMBLE AND INSTALL VLF ANTENNAS

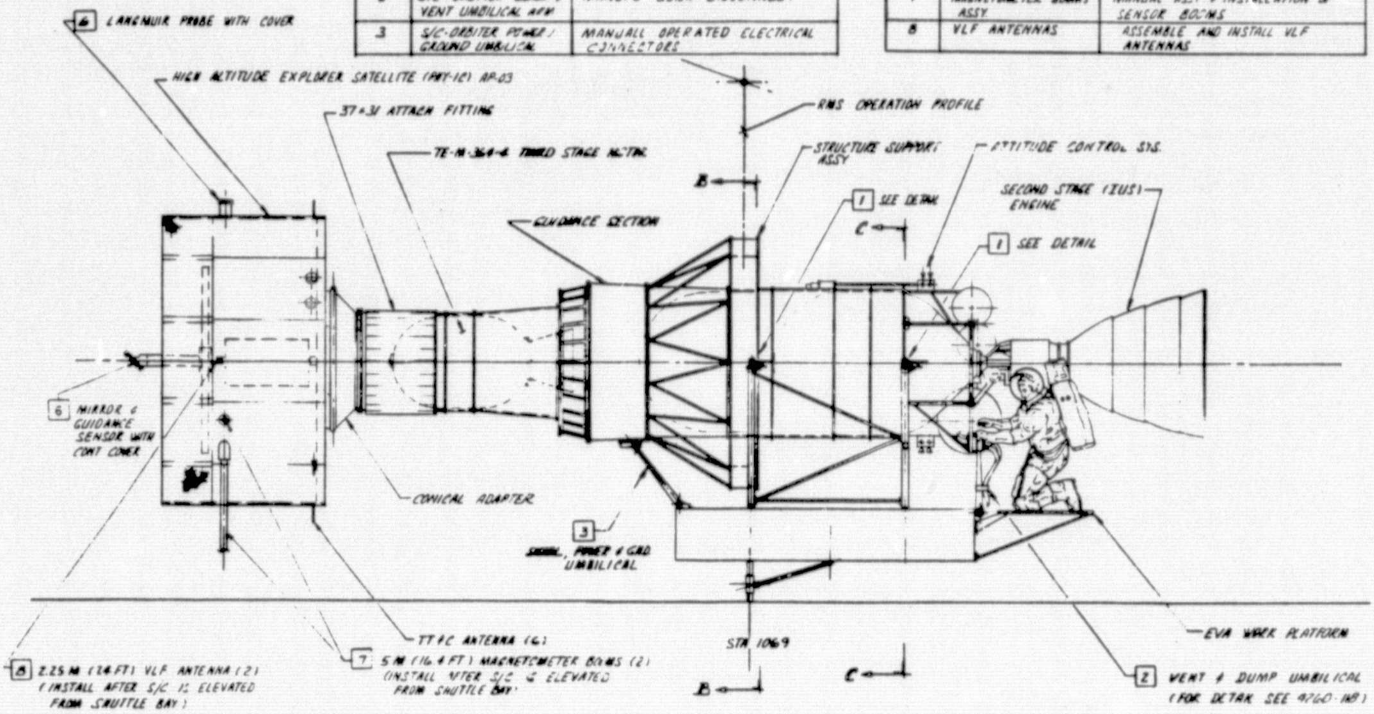


Figure 3-22. HAE Payload EVA Operations

Sequence Comparisons

The baseline versus EVA activity sequence comparisons is indicated in Table 3-8. All the required functions for the HAE delivery missions were referenced to the basic sequences. Special sequences were indicated for two contingency operations (7.3 and 7.4).

Timeline Comparisons

The automated versus EVA system timelines are compared in Figure 3-23. The total times for the operations are 10.2 hours and 11.0 hours respectively. The major portion of this time is a relatively lengthy HAE automated test and checkout procedure prior to release. The times required excluding checkout are 2.2 hours for the baseline and 3.0 hours for the EVA operations.

Table 3-8.
HIGH ALTITUDE EXPLORER (HAE)
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
1. PRE-OPERATIONS			
1.1 REMOVE CONTAMINATION SHIELDS (Star tracker)			
Basic sequences			
1.2 DISENGAGE BOOST LOCKS			
Appendages not deployed until upper stage propulsive maneuvers completed			
1.8 TEST, CHECKOUT (Instrumentation and subsystems)			
Basic sequences except antennas and solar panels fixed on HAE			
1.10 VISUAL INSPECTION (Pre-release inspection)			
Basic sequences			
1.11 REMOVE PYRO SHORTING PLUGS (IUS/spacecraft release system)			
Basic sequences			
1.13 POWER DEADFACE AND SWITCHOVER (Spacecraft/IUS power)			
Basic sequences			
3. CONTINGENCY OPERATIONS			
3.3 ENABLE/DISABLE SIGNAL/POWER PATHS (Malfunctioning circuits)			
Basic sequences			
3.4 PHOTO/TV COVERAGE (Malfunctioning mechanisms)			
Basic sequences			
3.5 EQUIPMENT DISASSEMBLY (Malfunctioning components)			
Basic sequences			
3.6 MECHANISM REPAIR (Malfunctioning components)			
Basic sequences			
3.7 TROUBLESHOOTING (Malfunctioning subsystems)			
Basic sequences			
3.8 MODIFICATION (Malfunctioning subsystems)			
Basic sequences			
4. SEPARATE SPACECRAFT			
4.1 REMOVAL UMBILICAL (Orbiter to Spacecraft/upper stage)			
Basic sequences			
4.2 DISENGAGE SPACECRAFT BOOST LOCKS			
Basic sequences			
4.3 TRANSFER TO SPACECRAFT GROUND			
Basic sequences			
5. DOCKING OPERATIONS			
5.3 DIRECT PLACEMENT (Contingency recovery of spacecraft after release from orbiter but prior to upper stage ignition)			
Basic sequences			
5.4 ENGAGE DOCKING LATCHES (4 latches)			
Basic sequences			

Table 3-8. (continued)
HIGH ALTITUDE EXPLORER (HAE)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	**Payload Functional Reqmts.**	**Sequence**	**Payload Functional Reqmts.**
5.5 CONNECT UMBILICAL (Orbiter to payload umbilical)			
Basic sequences			
5.6 CONNECT TO SHUTTLE GROUND			
Basic sequences			
7. PREPARE FOR RETURN (CONTINGENCY ONLY)			
7.1 INSTALL CONTAMINATION SHIELDS (Star tracker)			
Basic sequences			
7.2 ENGAGE ENTRY LATCHES (Spacecraft to IUS - 2 latches)			
Basic sequences			
7.3 REMOVE INSTRUMENTS (2 magnetometers)			
Instruments remain mounted in automated mode		Proceed to work platform	Handholds, etc.
Inspect instruments for entry	CCTV in bay	Remove 2 magnetometers	Hand tools, light
		Store magnetometers in orbiter cabin	Carrying pouch
7.4 ENGAGE RMS/OPERATE STOW DEVICE			
Activate RMS circuit	RMS control station	Proceed to work platform	Handholds, foot restraints
Attach RMS to payload	End effector, RMS control station	Observe RMS movement to attachment interface	Light source
Move spacecraft to final attach position	RMS control station	Close RMS end effector on payload attachment interface	Lever operated end effector
Provide visual display of final lineup	CCTV in payload bay,	Guide movement of spacecraft	Light source
7.7 STOW/LOCK REMOVED COMPONENTS			
Basic sequences			
7.9 INSPECT FOR ENTRY			
Basic sequences			
7.10 INSTALL SHORTING PLUGS			
Basic sequences			
7.11 POWER DEADFACE AND SWITCHOVER			
Basic sequences			
7.12 DRAIN/PURGE FLUID SYSTEMS (Cold gas for attitude control)			
Basic sequences			

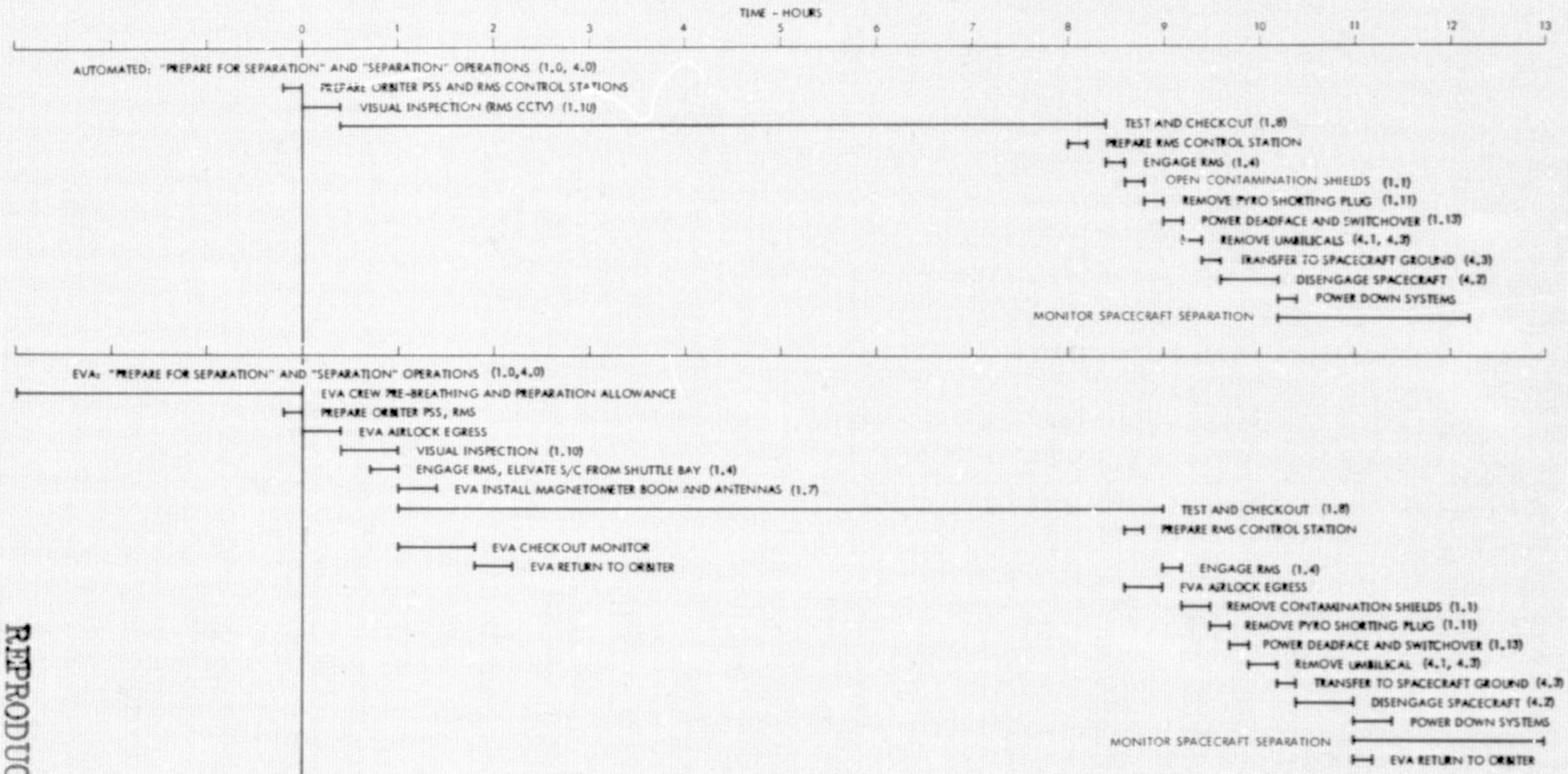


Figure 3-23. HAE - Preparation for Operation, Baseline and EVA Modes

3.8 U.S. DOMSAT C

The U.S. Domestic Communication Satellite "C" (DOM) assembly is illustrated in Figure 3-24. The representative payload consists of an assembly of three satellites to be delivered to a low inclination geosynchronous orbit. The assembly is shown mounted on top of a Tug vehicle. The spacecraft designs shown are based on Space Division-developed concepts.

The mission equipment for the DOM payloads consists primarily of several transceivers working in low, medium, and high data rate ranges. Other equipment will include a frequency source, S-band tracking system, Ku-band beacon, and related cabling and waveguides.

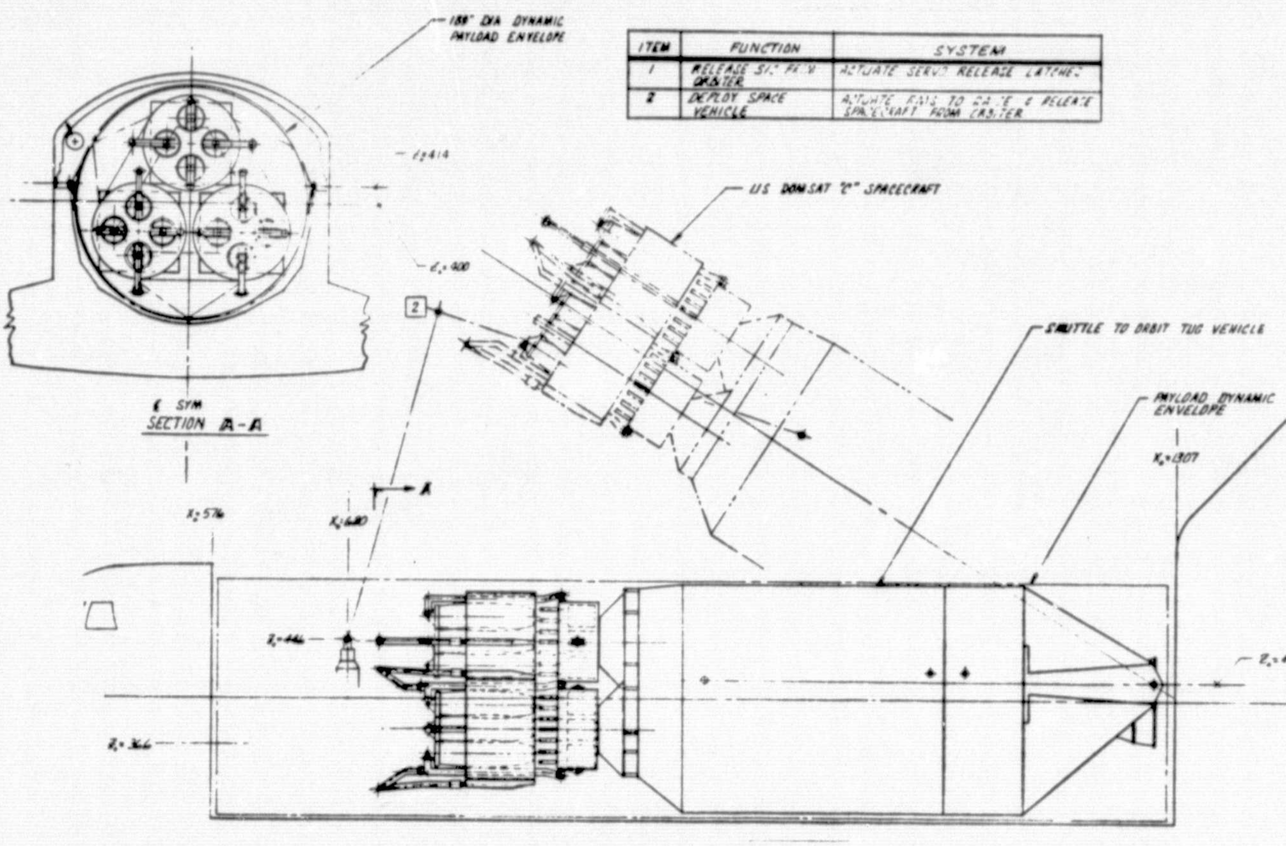


Figure 3-24. Baseline DOMSAT Payload

The Tug system will provide the support required for achieving the operational orbit. Special spacecraft-to-Tug interface structure will be required to release the spacecraft automatically after achieving the operational orbit. After release of the DOM, ground commands will release solenoid-operated solar panel struts and allow antennas to be unfurled. The interface structure will then be returned to the orbiter together with the Tug for reuse for future launches or possible retrieval missions.

The DOMSAT program defined consists of delivery missions in 1983 and 1988. Each delivery consists of placing three spacecraft into a low inclination geosynchronous orbit (35,780 km). Potential retrieval and/or servicing of DOM was not analyzed.

The mission objectives for DOM are to provide forward and return telecommunication links for low, medium, and high data rate satellites in earth orbit. The DOM will provide data links from satellite to satellite as well as links between satellites and ground stations. Of the three satellites delivered simultaneously, two are translated into operational longitude locations about the equator while one is retained as an on-orbit spare.

3.8.1 Baseline Payload Operations Definition

PSS preparation and visual inspection, test and checkout operations for the payload and Tug assembly will be performed while the assembly remains in the orbiter bay. The group of three spacecraft will not be disassembled to check deployment of DOM mechanisms for the delivery missions.

After partial systems and subsystems checkout is completed, mechanisms will be actuated to release boost latches, remove pyro shorting plugs, switch over power, and remove umbilicals. The RMS will then extend the spacecraft assembly and stabilize and release the unit. The payload release and separation operations are primarily tug functions which are not analyzed in the present study.

3.8.2 EVA Applications

The assembly of three DOMSATS attached to a high technology Tug almost fills the orbiter payload bay and, therefore, limits access. Separation of the three spacecraft for detailed mechanism testing was examined for EVA applications but did not appear to be attractive due to the complexity of the operation. After completion of the partial spacecraft and Tug systems and subsystems checkout, EVA is utilized for spacecraft and Tug visual inspection, to remove pyro shorting plugs, to release latches, switch over power, and release umbilicals.

3.8.3 Operations Analysis

Operations Cycle

Figure 3-1 block diagram depicts the major operations cycle for the DOMSAT delivery mission. These operations include assembling the three DOMSAT's to a special platform and mating this with a high energy Tug to deliver the assembly to the geosynchronous orbit. The diagram also indicates a contingency cycle and the return of the Tug to the orbiter vicinity and recovery for return to earth for reuse. In the case of the DOMSAT, blocks 10.12 and 10.15, etc., would be required on each normal delivery mission for Tug only (where a reusable Tug is involved), as well as on DOMSAT retrieval missions.

Sequence Comparisons

The delivery mission activity sequence comparisons for the DOMSAT program are summarized in Table 3-9. Because of the complexities of the three spacecraft assembly for the payload, few significant EVA operations were performed. The operations for separation of the payload from the Shuttle orbiter would be standard Tug functions which were not analyzed in the current study.

Table 3-9.
U.S. DOMSAT (DOM) DELIVERY MISSION
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
1. PRE-OPERATIONS			
1.1 REMOVE CONTAMINATION SHIELDS (2 horizon sensors)			
Automated functions would be delayed until reaching synchronous orbit		EVA can use basic sequence	
1.8 TEST/CHECKOUT (Instrumentation and subsystems)			
Activate checkout console and electronics	PSS control console	Tug launch of three payloads to synchronous altitude precludes testing of mechanical systems at orbiter altitude. Therefore, no EVA assistance for test and checkout would be planned. Opearations are same as for automated sequences.	
Test power and electronic circuits	PSS checkout console		
Check spacecraft subsystems	PSS checkout console		
Power down test and check-out operations			
1.10 VISUAL INSPECTION (3 spacecraft)			
Basic sequences			
1.11 REMOVE PYRO SHORTING PLUGS (3 spacecraft)			
Basic sequences			
1.13 POWER DEADFACE AND SWITCHOVER (3 spacecraft)			
Basic sequences			
3. CONTINGENCY OPERATIONS			
3.3 ENABLE/DISABLE SIGNAL/POWER PATHS (Malfunctioning circuits)			
Basic sequences			
3.4 PHOTO/TV COVERAGE (Malfunctioning mechanisms)			
Basic sequences			
3.5 EQUIPMENT DISASSEMBLY (Malfunctioning components)			
Basic sequences			
3.6 MECHANISM REPAIR (Malfunctioning components)			
Basic sequences			
3.7 TROUBLESHOOTING (Malfunctioning subsystems)			
Basic sequences			
3.8 MODIFICATION (Malfunctioning subsystems)			
Basic sequences			

Table 3-9. (continued)
U.S. DOMSAT (DOM) DELIVIERY MISSION
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
4. SEPARATE SPACECRAFT			
4.1 REMOVE UMBILICAL (Orbiter to spacecraft/upper stage)			
Basic sequences			
4.2 DISENGAGE SPACECRAFT BOOST LOCKS			
Basic sequences			
4.3 TRANSFER TO SPACECRAFT GROUND			
Basic sequences			
5. DOCKING OPERATIONS			
5.3 DIRECT PLACEMENT (Contingency recovery of spacecraft after release from orbiter but prior to upper stage ignition)			
Basic sequences			
5.4 ENGAGE DOCKING LATCHES (4 latches)			
Basic sequences			
5.5 CONNECT UMBILICAL (Orbiter to payload umbilical)			
Basic sequences			
5.6 CONNECT TO SHUTTLE GROUND			
Basic sequences			
7. PREPARE FOR RETURN			
7.1 INSTALL CONTAMINATION SHIELDS (Star tracker)			
Basic sequences			
7.2 ENGAGE ENTRY LATCHES (Spacecraft to IUS - 2 latches)			
Basic sequences			
7.3 REMOVE INSTRUMENTS			
Instruments remain mounted in automated mode		Proceed to work platform	Handhold, etc.
Inspect instruments for entry	CCTV in bay	Remove instruments, if required	Hand tools, light
		Store instruments in Shuttle bay	Entry tie-downs
7.4 ENGAGE RMS/OPERATE STOW DEVICE			
Activate RMS circuit	RMS control station	Proceed to work platform	Handholds, foot restraints
Attach RMS to payload	End effector, RMS control station	Observe RMS movement to attachment interface	Light source
Move spacecraft to final attach position	RMS control station	Close RMS end effector on payload attachment interface	Lever operated end effector
Provide visual display of final lineup	CCTV in payload bay	Guide movement of spacecraft	Light source

Table 3-9. (continued)

U.S. DOMSAT (DOM) DELIVERY MISSION

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
7.7 STOW/LOCK REMOVED COMPONENTS			
Basic sequences			
7.9 INSPECT FOR ENTRY			
Basic sequences			
7.10 INSTALL SHORTING PLUGS			
Basic sequences			
7.11 POWER DEADFACE AND SWITCHOVER			
Basic sequences			
7.12 DRAIN/PURGE FLUID SYSTEMS (Cold gas for attitude control)			
Basic sequences			

Timeline Comparisons

The timeline comparisons for the DOM baseline and EVA versions of the DOM delivery mission are shown in Figure 3-25. As noted earlier, no significant difference in timelines was estimated. Total time was approximately 2.7 hours with 1.6 hours with checkout excluded.

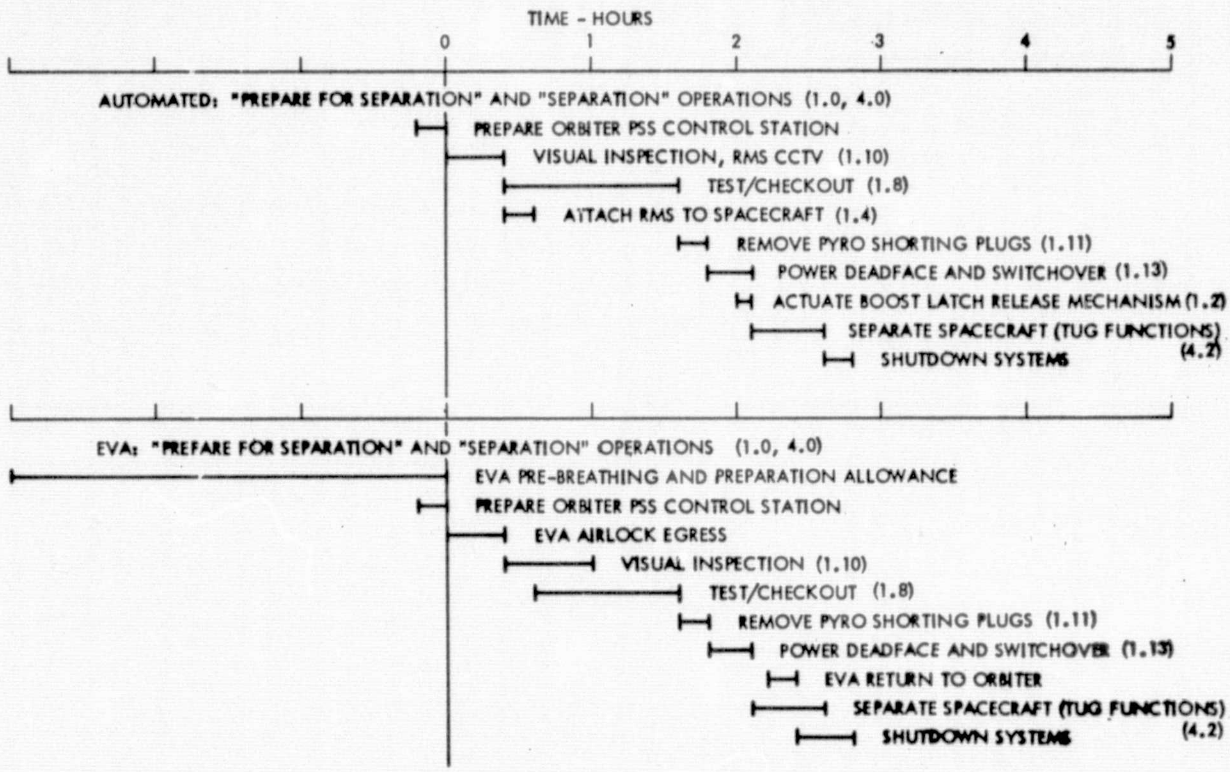
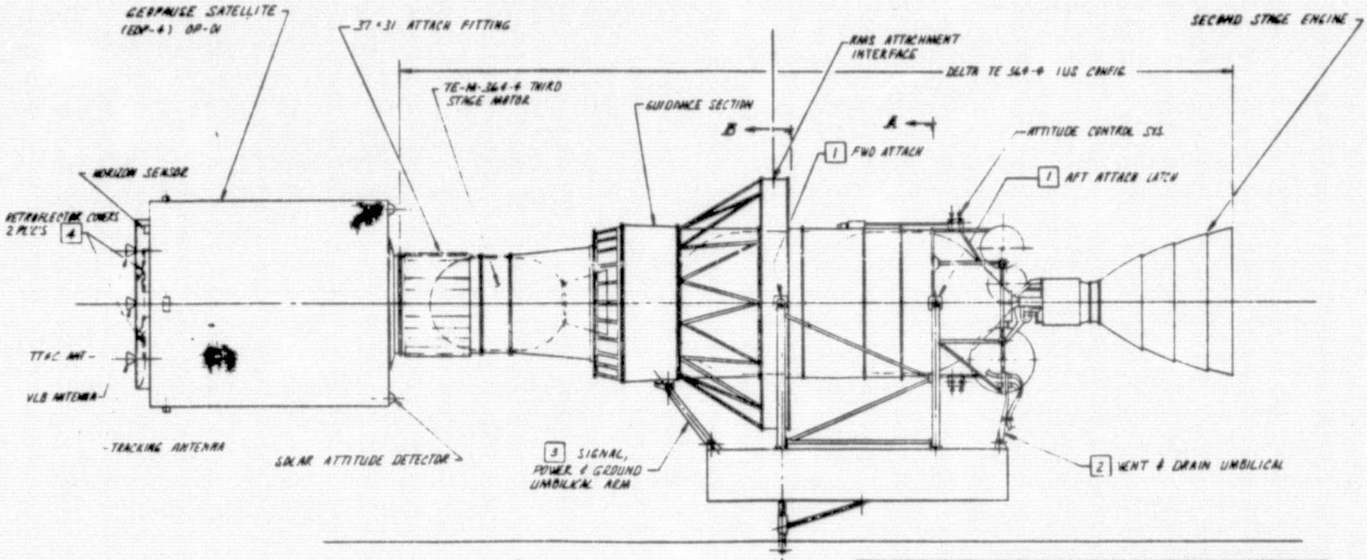


Figure 3-25. DOM - Preparation for Operation, Baseline and EVA Modes

3.9 GEOPAUSE

The baseline Geopause (GEO) representative payload is illustrated in Figure 3-26. The payload is shown mounted on a Delta TE 364-4 IUS. The general mounting and operational arrangement is very similar to that for the HAE payload described earlier.



ITEM	FUNCTION	SYSTEM
1	UNLATCH PAYLOAD TIE-DOWN MECHANISM	ACTUATE SERVO MECHANISM TO RELEASE CAPTURE LATCHES
2	S/C-ORBITER DRAIN & DRAIN UMBILICAL	SERVO ACTUATED DISCONNECT OF DRAIN & VENT UMBILICAL SWING ARM
3	S/C ORBITER POWER & GROUND UMBILICAL	SERVO ACTUATED DISCONNECT OF POWER & GROUND UMBILICAL SWING ARM

Figure 3-26. Baseline Geopause Payload

The mission equipment for the GEO consists of two retroreflector arrays, a tracking link precision transmitter/receiver/transponder system, and a very long baseline interferometer.

The Geopause satellite is classified as a current design expendable spacecraft. The study traffic model includes only one delivery launch, that in 1982. The GEO is an earth and ocean physics discipline payload to be launched in a 90-degree inclination, 30,000 km altitude orbit. This will result in an orbital period of approximately 20 hours.

The program objective is to provide precise tracking of the satellite to help improve uncertainties in orbit determination, tracking system biases, gravity field values, and ground station locations. The system will provide a 10 centimeter analysis capability. The mission results to the 10 cm accuracy, will assist a number of earth and ocean dynamics investigations. These include studies of earthquake fault motions, earth tides, gravity fields, and sea-surface topography.

3.9.1 Baseline Payload Operations Definition

The automated routine of spacecraft and upper stage activation and checkout utilizes the orbiter CCTV for a visual check of all accessible surfaces and mechanisms. The various subsystems are then subjected to the planned checkout procedures from the PSS.

At the conclusion of the systems checkout, the RMS will be attached to the payload and the boost latches released by activation and operation of the servo-mechanisms. Other mechanisms will be operated to remove sensor contamination shields, remove pyro shorting plugs, and disconnect umbilicals. The payload will then be translated out of the payload bay by the RMS to the position for release. After release the orbiter will separate from the payload to the location planned for monitoring the additional payload test and checkout procedures. The automated operations from start of visual inspection to payload release were estimated to require 3.8 hours.

3.9.2 EVA Applications

Several of the areas in which EVA tasks were substituted for automated mechanism operations are noted in Figure 3-27. EVA operations include manual disengagement of boost latches, manual removal of contamination covers, manual disconnect of power and ground umbilical, and manual disconnect of the fluid drain and vent umbilical. EVA also would be used in the visual inspection routine.

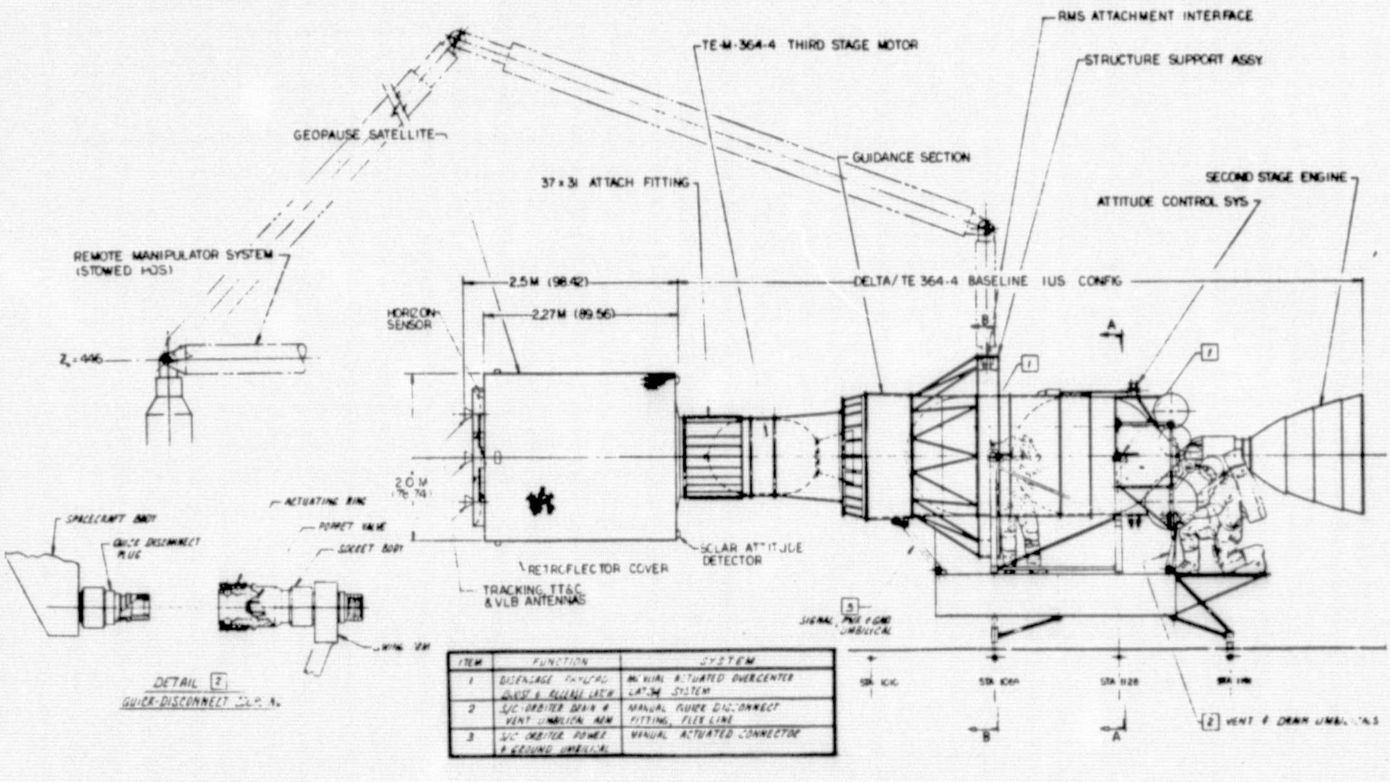


Figure 3-27. GEO Payload EVA Operations

3.9.3 Operations Analysis

Operations Cycle

The operational cycle for the GEO program is illustrated in Figure 3-1. The integration of the spacecraft with an IUS is required (10.3) since the high altitude orbit is beyond the capability of the Shuttle orbiter delivery.

Sequence Comparisons

Table 3-10 summarizes the activity sequence comparisons between the baseline and EVA-serviced payloads. It was estimated that the basic sequence operations were representative for the GEO delivery mission pre-operations and spacecraft separation operations.

Timeline Comparisons

The timelines for the baseline and EVA assisted operations are illustrated in Figure 3-28. Total times were 3.6 hours for the automated sequence and 4.4 hours for the EVA operations. Total times excluding the automated checkout time were 1.6 hours and 2.4 hours respectively.

TABLE 3-10.

GEOPAUSE (GEO)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
PRE-OPERATIONS			
1.1 REMOVE CONTAMINATION SHIELDS (Horizon sensor, sun sensors (2))			
Basic sequences			
1.2 DISENGAGE BOOST LOCKS			
Basic sequences			
1.8 TEST, CHECKOUT (Instrumentation and subsystems)			
Basic sequences			
1.10 VISUAL INSPECTION (Pre-release inspection)			
Basic sequences as applicable			
1.11 REMOVE PYRO SHORTING PLUGS (IUS, pyro disconnects)			
Basic sequences			
1.13 POWER DEADFACE AND SWITCHOVER			
Basic sequences			
1.14 FILL FLUID SYSTEMS (Attitude control nitrogen gas)			
Basic sequences			
4. SEPARATE SPACECRAFT			
Basic sequences			

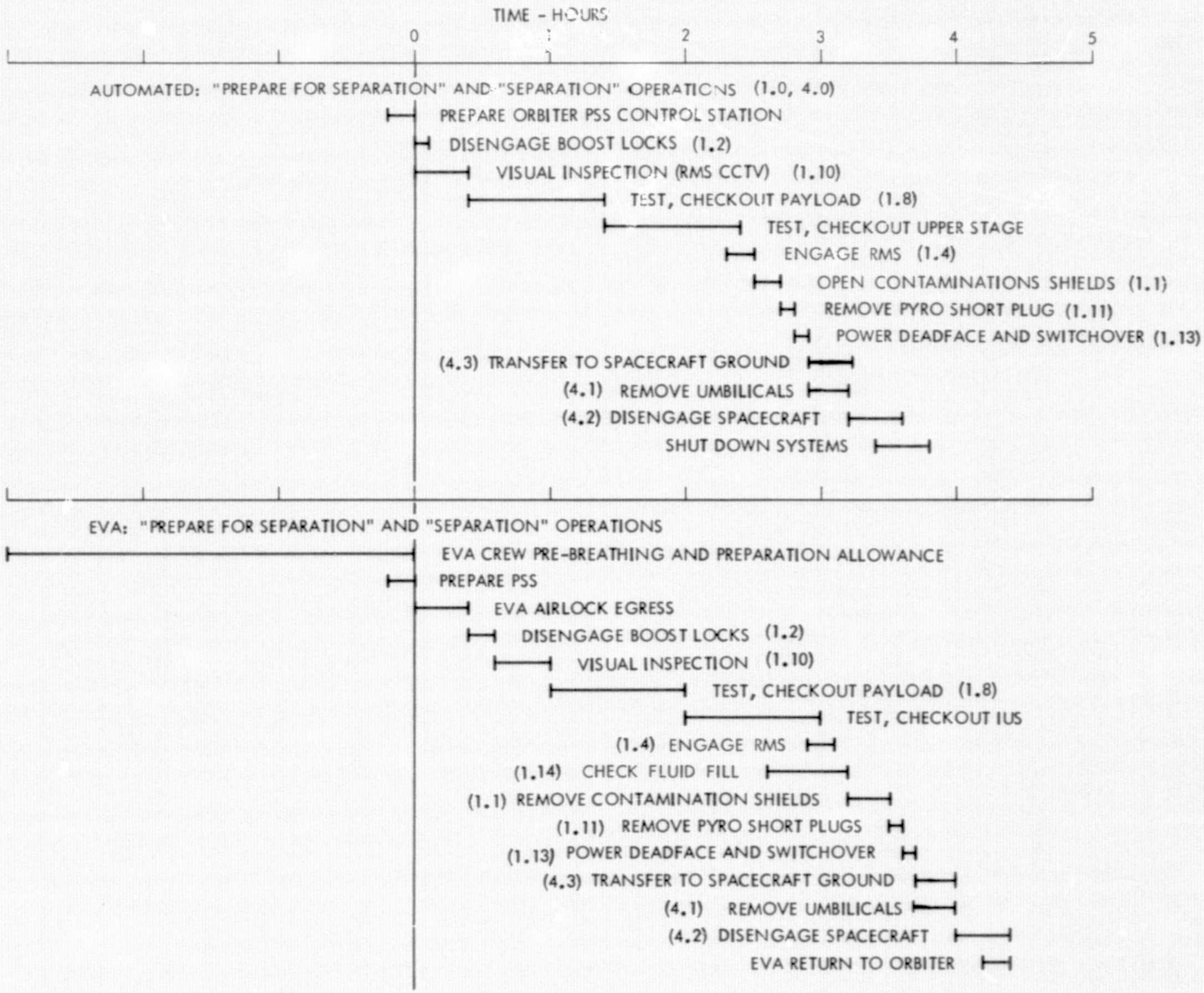


Figure 3-28. GEO - Preparation for Operation, Baseline and EVA Modes

3.10 MARINER JUPITER ORBITER

The Mariner Jupiter Orbiter (MJO) and upper stage assembly is illustrated in Figure 3-29. A Centaur upper stage, as illustrated, provides the escape velocity after delivery of the assembly to earth orbit by the Shuttle. A special feature of the illustrated design is the RTG electrical power unit which will require special handling both on-orbit and prelaunch operations. A protective shroud covering the entire spacecraft is also illustrated.

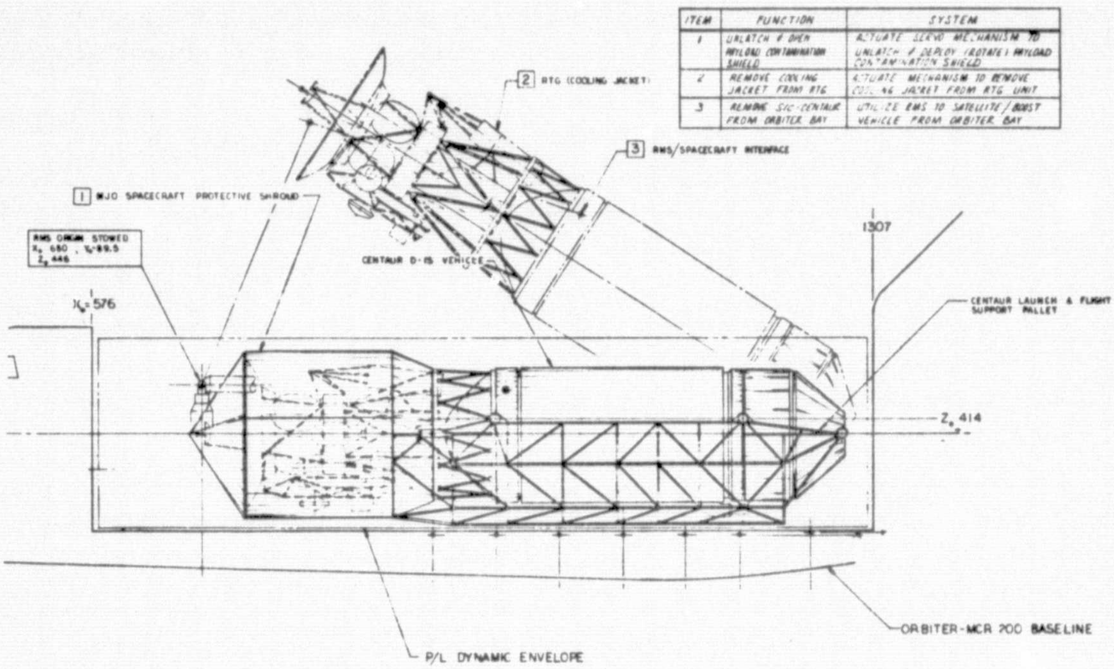


Figure 3-29. Baseline MJO Payload

The Mariner Jupiter Orbiter spacecraft will provide the platform from which an investigation of Jupiter, its satellites and surrounding space can be made. Studies will include Jovian planetology, particles and fields, radio occultation and emissions, celestial mechanics and survey of the interplanetary space. Two MJO delivery launches are planned, both in 1981. The spacecraft have been classified as low cost expendable in the NASA traffic model.

3.10.1 Baseline Payload Operations Definition

The automated routine of MJO activation and checkout starts with a visual inspection of the assembly after preparation of the orbiter PSS and RMS control stations. Two of the unique characteristics of the MJO representative payload are the proposed protective cover for the spacecraft and the RTG power system for the MJO flight operations.

The protective shroud shown previously, encloses the entire MJO forward of the Centaur propulsion stage. This cover is attached to the orbiter structure and provides protection of sensitive surfaces of the spacecraft during the final stages of ground operations prior to launch and during the ascent to orbit. After the initial on-orbit visual inspection with the orbiter CCTV, the mechanisms for unlatching the shroud cover shield segments and for rotating the segments will be operated. (The RMS is a potential alternative for segment rotation.) Visual inspection of the MJO will then be continued.

The RTG electrical power system requires special cooling while in the orbiter. It was assumed for this study that a circulating water jacket surrounding the power element will be designed to slide to one end of a cylindrical shaped RTG and then be rotated to the side of the spacecraft to provide clearance for MJO removal from the orbiter bay.

Concurrently with the removal of the RTG jacket, other subsystems of the spacecraft and upper stage will be checked and prepared for separation. As soon as checkout is completed, the orbiter-to-spacecraft umbilicals and other separation mechanisms will be operated. The RMS will then translate the payload to the release position. After release, the orbiter will translate from the payload. The orbiter will perform a fly-around inspection as the payload free-flight checkout is performed. After completion of this sequence, the orbiter will monitor the spacecraft departure.

3.10.2 EVA Applications

Suggested EVA functions are illustrated in Figure 3-30, and include manual actuation of spacecraft protective shield latches, manual opening of protective shield segments, removal and storage of RTG cooling jacket, inspection of payload, and umbilical and payload boost latch release. After the spacecraft is translated out of the orbiter payload bay, the protective shield is closed and latched for entry. The amount of time the EVA crewman spends in the payload bay after the RTG cooling coil removal is kept to a minimum because of the increasing radiation level.

3.10.3 Operations Analysis

Operations Cycle

The operations cycle for the MJO spacecraft is illustrated in Figure 3-1. Normal delivery operations and possible contingency operations are included in the event that on-orbit checkout revealed spacecraft anomalies. The value of EVA contingency operations for this class of mission is potentially enhanced by the launch window constraints normally encountered. A requirement to return a malfunctioning planetary spacecraft to the earth for repair may result in a missed opportunity, whereas on-orbit repair could potentially result in a fully operational spacecraft within the allowable window.

Sequence Comparisons

The activity sequence comparisons between baseline and EVA-serviced MJO payloads are summarized in Table 3-11. The major unique features for MJO on-orbit

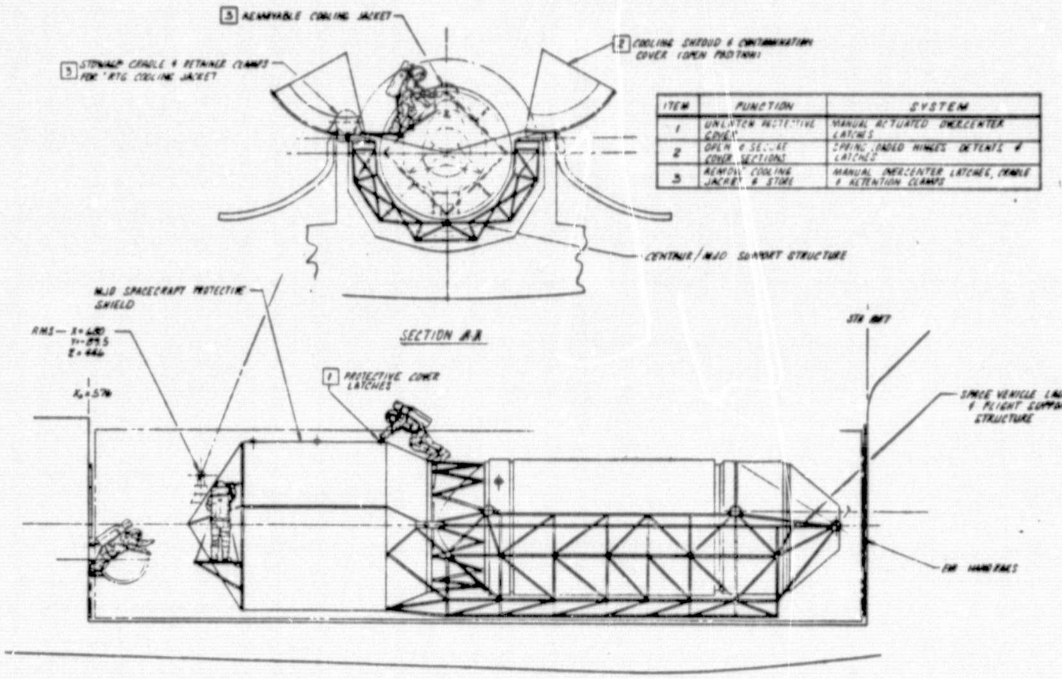


Figure 3-30. MJO Payload EVA Operations

operations were estimated to occur in the handling of the spacecraft contamination shield and in RTG power pack activation. Other "prepare for separation" operations are referenced to the basic sequence activities.

Timeline Comparisons

The timelines for the automated and EVA versions of on-orbit operations are shown in Figure 3-31. On-orbit test and checkout while attached to the orbiter are minimized to reduce the radiation hazard from the RTG. Operations times excluding checkout were estimated at 2.1 hours for the baseline and 2.3 hours for the EVA assisted operations.

Table 3-11.

MARINER JUPITER ORBITER (MJO)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
1.1.1 REMOVE CONTAMINATION SHIELDS (MJO spacecraft shroud)			
Activate power circuits for contamination shield	PSS control console, RMS control console	Proceed to EVA work platforms	Handholds, foot restraints, platforms
Operate shroud latch mechanisms to open position	Electromechanical latches	Open MJO contamination shroud latch mechanism	Manual operating latches
Verify latch open positions	Event sensing microswitches	Open contamination shroud covers	Manual operating lever mechanisms
Open MJO contamination shroud covers	RMS	Latch covers in open position	Manual operating latches
Lock shroud covers in open position	Electromechanical latches		
1.1.2 REMOVE CONTAMINATION SHIELDS (Sun sensors, star tracker)			
Basic sequences			
1.8 TEST, CHECKOUT			
Basic sequences			
1.10 VISUAL INSPECTION			
Basic sequences			
1.11 REMOVE PYRO SHORTING PLUGS			
Basic sequences			
1.12 POWER PACK (RTG) ACTIVATION			
Activate power circuits for RTG cooling jacket removal	PSS control console, RMS control	Proceed to RTG work station	Handholds, work platform
Operate cooling jacket hold-down latch mechanism	Electromechanical latches (2)	Unlatch cooling jacket restraints	Manual operating latches
Verify hold-down latches in open position	Event sensing microswitches	Slide cooling jacket off RTG assembly	Manual operation
Slide cooling jacket off RTG assembly, store jacket on cover door	RMS	Store cooling jacket assembly on jacket cover	Manual operation, manual operating storage latch
Secure cooling jacket in stored position	Electromechanical latch	Shut off water circulation for cooling jacket	PSS control on pump, manual operating water valves
Shut off cooling water circulation in cooling jacket	PSS control, solenoid switches for water line shutoffs	Activate circuits to connect RTG power output to spacecraft EPS	
Activate circuits to connect RTG power output to spacecraft EPS	PSS		
1.13 POWER DEADFACE AND SWITCHOVER			
Basic sequences or may be part of automated umbilical separation			

Table 3-11. (continued)

MARINER JUPITER ORBITER (MJO)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
4. SEPARATE SPACECRAFT			
4.1 REMOVE UMBILICAL (Orbiter to Spacecraft/upper stage)			
Basic sequences			
4.2 DISENGAGE SPACECRAFT BOOST LOCKS			
Basic sequences			
4.3 TRANSFER TO SPACECRAFT GROUND			
Basic sequences			
5. DOCKING OPERATION			
5.3 DIRECT PLACEMENT (Contingency recovery of spacecraft after release from orbiter but prior to upper stage ignition)			
Basic sequences			
5.4 ENGAGE DOCKING LATCHES (4 latches)			
Basic sequences			
5.5 CONNECT UMBILICAL (Orbiter to payload umbilical)			
Basic sequences			
5.6 CONNECT TO SHUTTLE GROUND			
Basic sequences			
7. PREPARE FOR RETURN (CONTINGENCY ONLY)			
7.1 INSTALL CONTAMINATION SHIELDS (Star tracker)			
Basic sequences			
7.2 ENGAGE ENTRY LATCHES (Spacecraft to IUS - 2 latches)			
Basic sequences			
7.3 REMOVE INSTRUMENTS			
Instruments remain mounted in automated mode		Proceed to work platform	Handholds, etc.
Inspect instruments for entry	CCTV in bay	Remove instruments if required	Hand tools, light
		Store instruments in orbiter bay	Instrument tie-downs
7.4 ENGAGE RMS/OPERATE STOW DEVICE			
Activate RMS circuit	RMS control station	Proceed to work platform	Handholds, foot restraints
Attach RMS to payload	End effector, RMS control station	Observe RMS movement to attachment interface	Light source
Move spacecraft to final attach position	RMS control station	Close RMS end effector on payload attachment interface	Lever operated end effector
Provide visual display of final lineup	CCTV in payload bay	Guide movement of spacecraft	Light source

Table 3-11. (continued)

MARINER JUPITER ORBITER (MJO)

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
7.7 STOW/LOCK REMOVED COMPONENTS			
Basic sequences			
7.9 INSPECT FOR ENTRY			
Basic sequences			
7.10 INSTALL SHORTING PLUGS			
Basic sequences			
7.11 POWER DEADFACE AND SWITCHOVER			
Basic sequences			
7.12 DRAIN/PURGE FLUID SYSTEMS (Cold gas for attitude control)			
7.13 POWER PACK (RTG) DEACTIVATION			
Inverse of 1.12			

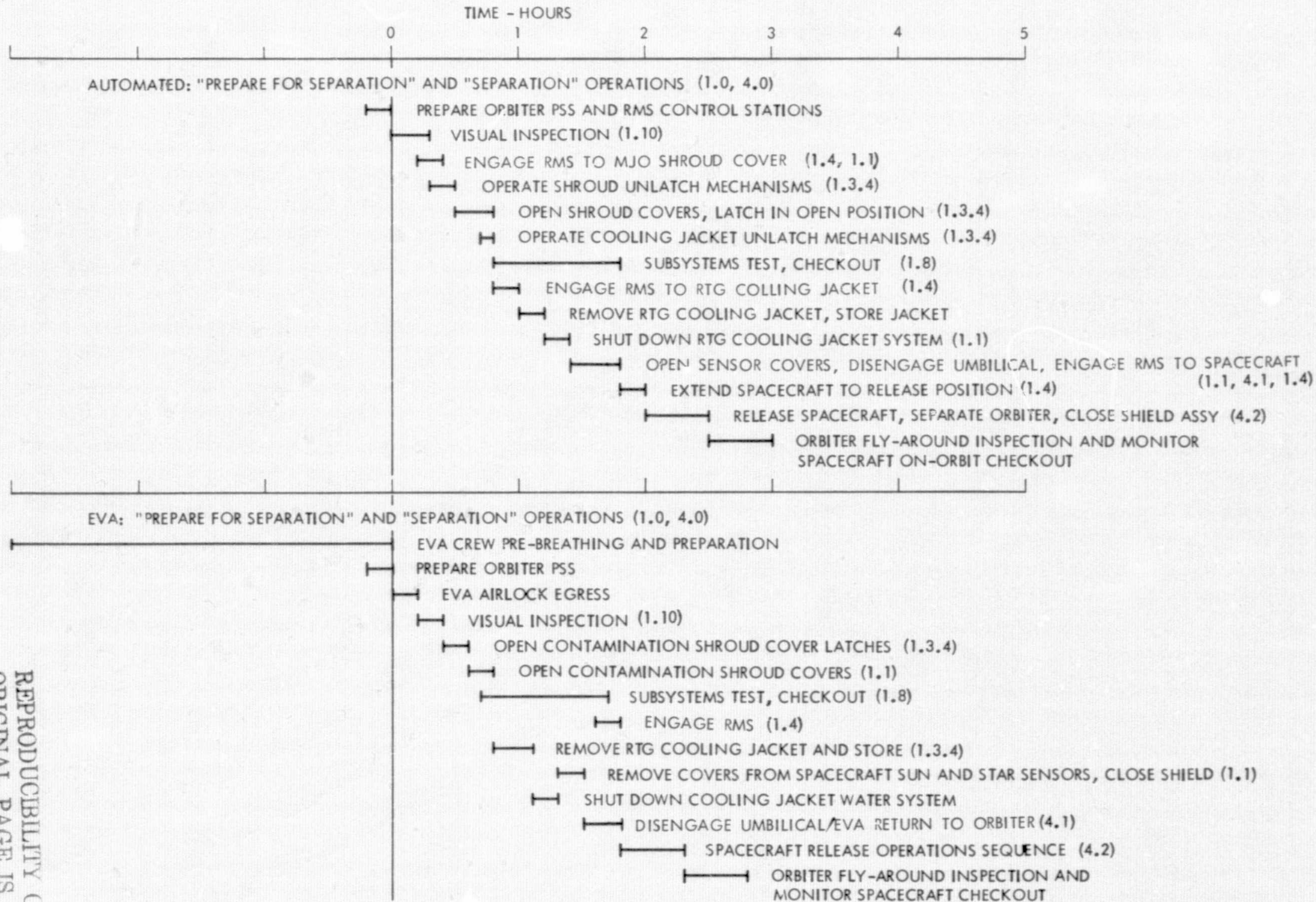
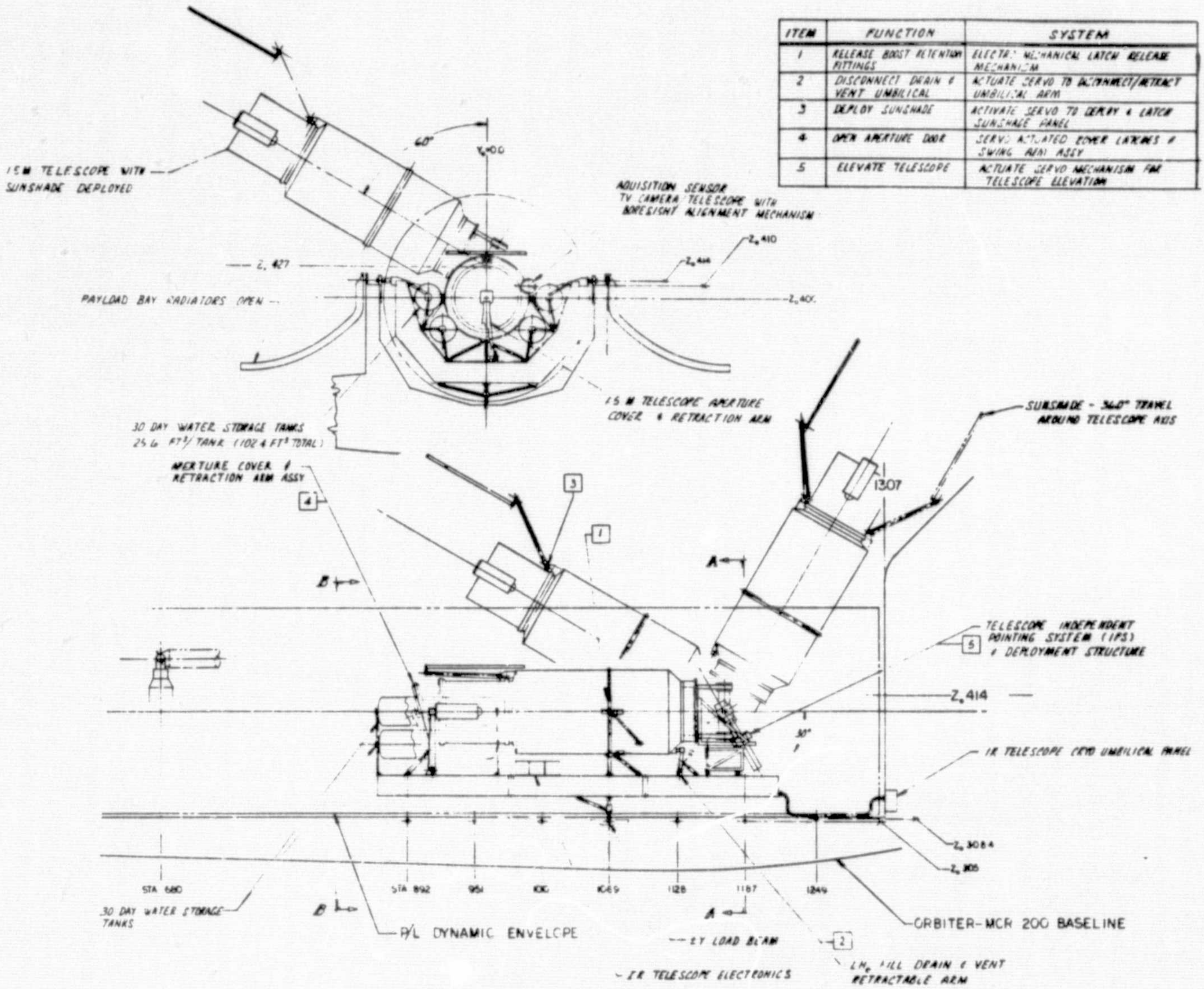


Figure 3-31. MJO - Preparation for Operation, Baseline and EVA Modes

Space Division
Rockwell International

3.11 SHUTTLE INFRARED TELESCOPE FACILITY (SIRTF)

The telescope baseline configuration was taken from the Shuttle System Payload Descriptions (SSPD) study and supplemented by data derived from the Rockwell SIRTF proposal and current ARC study activity. It is illustrated in Figure 3-32.



ITEM	FUNCTION	SYSTEM
1	RELEASE BOOST RETENTION FITTINGS	ELECTRO MECHANICAL LATCH RELEASE MECHANISM
2	DISCONNECT DRAIN & VENT UMBILICAL	ACTUATE SERVO TO DISCONNECT/RETRACT UMBILICAL ARM
3	DEPLOY SUNSHADE	ACTIVATE SERVO TO DEPLOY & LATCH SUNSHADE PANEL
4	OPEN APERTURE DOOR	SERVO ACTUATED COVER LATCHES & SWING ARM ASSY
5	ELEVATE TELESCOPE	ACTUATE SERVO MECHANISM FOR TELESCOPE ELEVATION

Figure 3-32. Baseline SIRTF Payload

Telescope. The telescope is approximately 2 meters in diameter and 6 meters long. The telescope barrel itself is a right circular cylinder whose axis is coincident with the optical axis.

A cryogen tank surrounds the inner housing. The cavity at the rear of the telescope contains the instruments. Forward of the inner housing are baffles to reject stray radiation. Between the inner housing and the front baffles is a thin flexible membrane and a boil-off gas purge system for contamination control.

The flexible membrane contains openings for clear aperture operation. The telescope is cooled by boil-off gases which are circulated via tubing attached to the inner housing, front baffles, and thermal radiation shields.

The front cover is attached to the pallet and provides support for the telescope during launch. It is removed from the telescope aperture by a mechanism attached to the pallet. The cover contains a cold background plate and sources for telescope calibration. Additional calibration sources are located near the secondary mirror. The cover is replaced for support and protection prior to landing. All principal telescope interface connections such as cryogen ports, electrical connectors, and evacuation ports are made at the rear of the telescope.

The telescope is supported in the mount by a flange provided on the outer housing near the center of gravity of the telescope. An internal calibration device is incorporated in the telescope to allow in-flight instrument operation checkout. The device includes a collimated blackbody and IR line sources.

Thermal Assembly. The thermal assembly is made up of cryogenically cooled thermal subassemblies, helium storage dewar, optics, baffle, and radiation shield. The dewar is an annular shaped container; the helium is maintained at 2.5 atmospheres, which exceeds the critical pressure, eliminating sloshing problems associated with liquid/vapor systems.

An extending sunshade is rotatable in order to continually protect the aperture from the sun. The rotation is simply controlled by a sun seeker and a servo system on the telescope. The shade, which is counterbalanced, does not physically interfere with the orbiter in any position.

Acquisition, Pointing, and Stabilization. The acquisition, pointing, and stabilization subsystem uses a television camera for target acquisition. The LOS of the television camera is bore-sighted to the optical axis of the telescope. A three-axis mount (e.g., the Spacelab Instrument Pointing System--IPS), provides manual and automatic tracking capabilities.

The mission of the SIRTF is to determine the physical processes, nature and structures of stars, galactic nebulae, interstellar matter, galaxies, and other infrared radiation sources across a 1000 μm spectral range. It will also be used to evaluate developments in infrared detector technology.

During the period of 1980 through 1991, four sortie flights are planned. Approximately one-third of the Shuttle bay volume remains available for sharing with some other compatible payload (specifically with those that are contamination free). The present concept is to fly the missions for seven-day duration with subsequent flights up to 30 days in duration.

3.11.1 Baseline Payload Operations Definition

As can be seen from the configuration shown, all preparation for operation tasks are performed remotely from the PSS. There may be a requirement for allowing the Shuttle and equipment to outgas; however, the precise length of time for this has not been determined. Estimates have ranged from 6.5 hours (reference SSPD) to as much as 36 hours.

If there is a firm requirement for the outgassing of materials, then other tasks prior to the removal and stowage of the contamination cover may be accomplished but the cover may not be removed until the time has elapsed or a safe reading on the contamination monitors is observed.

Monitor Contamination Level. A contamination level check is made to determine the cleanliness of the ambient environment and to be used as a reference point for subsequent contamination-level checks. Shoud the second check (which is performed later) prove satisfactory, the preparation sequence will continue. If not, then with at least two reference points an estimate can be made of when the environment might be ready to continue with the sequence.

Retract Thermal Isolators. During the launch phase the cryogenic jacket is firmly secured via thermal insulators which must be decoupled during normal operation. The driving device is assumed to be a slow moving system such that when removed, the structure is not perturbed and driven out of tolerance.

Activate Alignment/Focus System. Alignment and focusing systems are built into the aperture contamination cover allowing the system to be aligned and refocused while still completely secured. This time is also used to prepare the remote control panel in addition to energizing the alignment/focus devices. The following two tasks are performed in conjunction with this task.

Uncage Gyros and Mirrors. After satisfactorily energizing the alignment and focusing systems, the telescope gyros and mirrors must be uncaged and allowed to settle out.

Instrument Calibration and Operability. This is an integrated task where a calibration source mounted in the contamination cover is allowed to radiate onto each of the sensors mounted in the Multiple Instrument Container (MIC). It allows for providing an inflight calibration of each sensor. An average of nine minutes is allotted per sensor.

Contamination Check II. This contamination check of the Shuttle environment is made for the purpose of verifying the immediate vicinity is adequately free of contamination prior to removal of the contamination cover.

Deploy Sun Shield, Separate Front Contamination Cover and Stow. While the telescope is still securely fastened to the pallet, a remote command is sent to the sun shield control mechanism, unfolding it to its normal operational position with the deployment arm extending it outward.

The front contamination cover serve multiple purposes. It is a contamination cover serving as a seal to maintain a vacuum within the telescope and is a boost tie-down point. A remote command is sent to the cover sequencing the unlatching of the securing devices and the actuation of the cover tie-down arm which moves the cover away from the telescope aperture.

Unlock Gimbal Mount and Intermediate Support. Having undone the front tie down, the telescope intermediate support and aft gimbal mounts are then commanded to unlock. The intermediate support mechanism consists of motorized latches which restrict any movement or possibility of damage during launch.

Deployment of Telescope. The deployment task consists of commanding the IPS to raise the telescope above the Shuttle sill and to turn the telescope. At this time the IPS automatically controls the telescope.

Verify Computer Indexing. Having established a successful deployment of the telescope, the astronaut-scientist will then exercise the computer to determine if proper instrument indexing occurs. This task has been limited to no more than two separate inputs.

Verify Instrument Calibration. The IR sensors are cycled through a calibration verification by pointing the telescope into space and comparing the data with data obtained from the built-in calibration source (reference instrument calibration, discussed previously).

3.11.2 EVA Applications

The major EVA effort is exerted in the payload preparation for operation and preparation for entry. Normal mission operations are performed primarily from the PS station within the orbiter cabin. During normal mission operations the only EVA applications identified are jettison of water stored in bags and contingency operations.

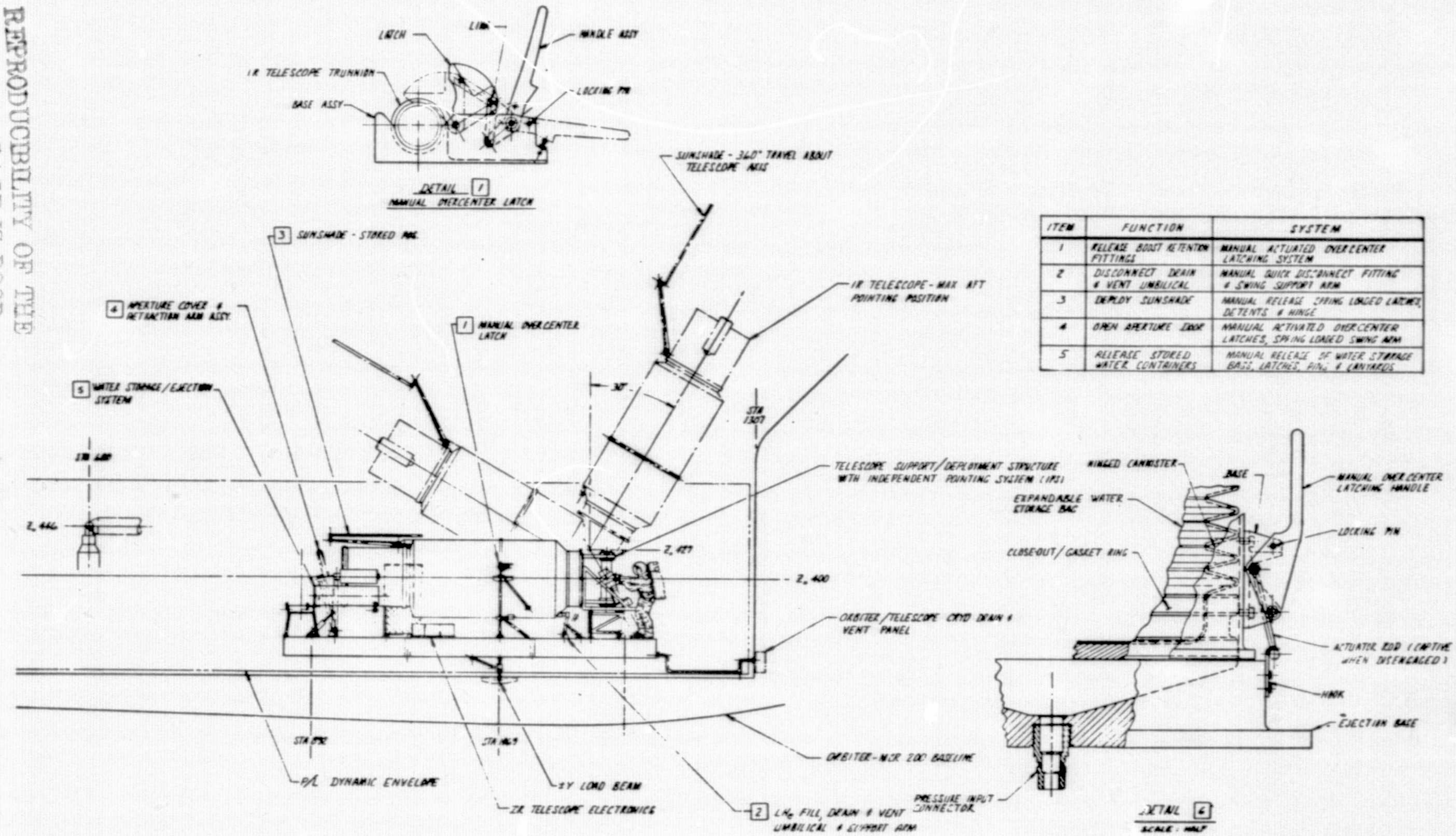
As reflected in Figure 3-33. the major tasks performed via EVA require the presence of a single astronaut. External contamination must be minimized in the vicinity of the telescope aperture. The extremely cold temperature will condense most contaminants thus reducing the intended effectivity of the investigation. Consequently, the EVA approach is to perform necessary activities near the aperture and then have the astronaut move away immediately following removal of the contamination cover. EVA applications are described below.

Deploy Sunshield. The basic sunshield deployment mechanism is retained from the automated version with the exception that the deployment force is astronaut-provided rather than automated. This eliminates such interfaces as controls, limit switches, motor drive, and talkback devices.

The EVA astronaut translates to the sunshield work station, secures his feet restraints, and actuates the sunshield to deploy it. Upon full deployment, the shield's latching mechanism self engages retaining the deployed configuration. The sunshield support arm is raised and pinned into position. The sunshield is attached to a drive ring which allows the sunshield to travel automatically about the telescope tube such that the aperture is always shielded from light and thermal effects.

Retract Thermal Isolators; Uncage Gyros and Mirrors. These two activities are discussed together since the tasks are related. They consist of stationing the astronaut behind the telescope (near the IPS) and manually driving out the thermal isolators similarly to the automated mode. Likewise, the control mechanism which uncages the gyros and mirrors is also manually operated from the same work station.

Remove Front Contamination Cover and Stow. In order to remove the aperture contamination cover, the EVA astronaut must translate over to the operator work



ITEM	FUNCTION	SYSTEM
1	RELEASE BOOST RETENTION FITTINGS	MANUAL ACTUATED OVERCENTER LATCHING SYSTEM
2	DISCONNECT DRAIN & VENT UMBILICAL	MANUAL QUICK DISCONNECT FITTING & SWING SUPPORT ARM
3	DEPLOY SUNSHADE	MANUAL RELEASE SPRING LOADED LATCHES, DETENTS & HINGE
4	OPEN APERTURE DOOR	MANUAL ACTIVATED OVERCENTER LATCHES, SPRING LOADED SWING ARM
5	RELEASE STORED WATER CONTAINERS	MANUAL RELEASE OF WATER STORAGE BAGS, LATCHES, PINS & LANYARDS

Figure 3-33. SIRTF Payload EVA Operations

station. He secures himself and releases each of the cover latches. The cover is also attached to a support arm which acts as a boost-locking device for the telescope, and a retraction and locking device. As the cover latches are released, a spring-loaded device acts against the support arm and gently pulls the cover from the telescope aperture to a point where the arm engages a stowage lock. There, the cover remains throughout the mission until replacement for entry or for recalibration.

It is important at this time that the EVA astronaut leave the vicinity of the aperture as soon as possible to reduce the amount of contaminant exuded from his suit.

Intermediate Telescope Latches and IPS. The final task prior to deploying the telescope beyond the mold line of the Shuttle is to unlatch the telescope intermediate supports and to unlock the instrument pointing system.

The astronaut translates to the intermediate support structure and releases a manual over-center latch at two pla-es (reference Item 1, Figure 3-33). From there he positions himself at the IPS work station where he secures himself, releasing the IPS locking mechanism. The IPS locking devices are such that the astronaut can perform the function from a fixed position and only require that his feet be restricted from movement.

Summary. A substantial number of tasks required to prepare this payload are performed remotely and similarly to the automated version. The primary EVA tasks consist of unlatching various devices and the telescope itself. Being an enclosed system and rather sensitive during operation, all the EVA tasks were felt necessary to be performed serially rather than in parallel. Consequently, this approach lends itself to a single EVA astronaut requirement.

3.11.3 Operations Analysis

Operations Cycle

The first-level operation cycle block diagram for the infrared telescope is shown in Figure 3-2. The basic cycle of operation is shown with more detail given for ground operations than was done for the automated spacecraft. This is due in part to the greater complexities presented with integration of various experiments, the Spacelab, and with the Shuttle orbiter.

On-orbit maintenance and refurbishment are not planned for sortie payloads in general and, therefore, are not discussed although they remain an operations option. Contingency activity is shown to reflect potential unforseen occurrences.

Sequence Comparisons

The on-orbit functional sequence comparisons for the SIRTF missions are summarized in Table 3-12. It is noted that the functional requirements do not contain a comprehensive listing matching that of the spacecraft missions. The reason being is that some of the functions are not compatible with sortie type missions; specifically 4.0 Separate Spacecraft, 5.0 Docking Operations, and some of the subfunctional requirements of the other major functional areas.

Table 3-12.
SHUTTLE INFRARED TELESCOPE FACILITY
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	**Payload Functional Reqmts.**	**Sequence**	**Payload Functional Reqmts.**
1. PRE-OPERATIONS			
Activate primary power bus to the facility and gimbal mechanism	PSS control console	Same	
		Proceed to telescope area	Handholds, foot restraints, and work platforms
1.1 REMOVE CONTAMINATION COVERS			
Depressurize telescope	Telescope internal pressure vent system	Depressurize telescope	Manual vent valves
		Unlatch, remove and stow front contamination cover	Cover latches, contamination cover, swing arm
Basic sequences			
1.2 DISENGAGE BOOST LOCKS (Gimbal latches, telescope, boost latches)			
Basic sequences			
1.3.4 ERECT SIRTF MECHANISM			
Partially erect telescope	PSS control console	Partial erection of telescope	PSS control console
1.3.3 ERECT SUNSHADE			
Unfold sunshade and lock	Sunshade latches and deployment mechanism	Manually unlatch, extend & deploy sunshade	Sunshade latches and sunshade
Extend sunshade arm	Sunshade deployment arm	Manually extend deployment arm	Deployment arm
1.8 TEST AND CHECKOUT			
Basic sequences			
1.10 VISUAL INSPECTION			
Basic sequences			
2. EXPERIMENT OPERATIONS			
Activate telescope system	PSS control console	Note: these functions are identical to the baseline mode	
Scan hemisphere locating IR sources	PSS control console, CCTV, computer		
Perform experiment per procedure	As required		
Monitor experiment data; change sensors	PSS control console, experiment sensors		
Perform manual scan for IR targets	PSS control console, IPS, computer		

Table 3-12. (continued)
SHUTTLE INFRARED TELESCOPE FACILITY
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
3. CONTINGENCY OPERATIONS			
3.1 RELEASE/OPERATE JAMMED MECHANISMS			
Basic sequences			
3.2 JETTISON/RETRACT/STOW FAILED EXTENDIBLES			
Basic sequences			
3.2 EQUIPMENT DISASSEMBLY			
Basic sequences			
6. PLANNED MAINTENANCE			
6.1 INSTALL PROTECTIVE COVERS			
Return telescope to Shuttle bay	PSS control console, IPS	Return telescope to Shuttle bay	PSS control console, IPS
Engage telescope barrel latches	PSS control console, latches	Engage telescope barrel latches, manually	Boost latches
Close telescope contamination cover, secure latches	PSS control console, contamination cover, swing arm, latches	Close telescope contamination cover, manually	Contamination cover, latches, cover swing arm
Basic sequences			
6.6 LOAD CRYOGENIC COOLANTS			
Engage cryogenic lines to telescope	PSS control console, cryo coupling	Connect cryo transfer line	Cryo transfer coupling swing arm
Perform transfer of cryogenics	PSS control console, cryo system	Pressurize cryo storage tank and transfer to telescope	Cryo system storage tank, transfer valves, pressure valves, control panel
		Close off transfer lines and vent pressure in cryo storage tank	Transfer valves, pressure vent valve
		Decouple transfer lines	Cryo transfer coupling, swing arm
6.9 SERVICE FLUID SYSTEM			
Collect fuel cell water	PSS control console, water storage tanks	Proceed to work station (almost every third day)	Handholds, food restraints, work platform
Jettison water	PSS control console, water evaporator unit	Disconnect water bag no. 1 & erect jettison mechanism no. 1	Quick disconnector, jettison mechanism
		Jettison water bag no. 1	Jettison ejector system no. 1
		Disconnect water bag no. 2 & erect jettison mechanism no. 2	Quick disconnector, jettison mechanism

Table 3-12. (continued)

SHUTTLE INFRARED TELESCOPE FACILITY

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
		Jettison water bag no. 2	Jettison ejector system no. 2
		Install 2 new water bags	Water bags, quick disconnectors
		Position jettison mechanism horizontally	Jettison mechanism & latches
7. PREPARE FOR RETURN			
7.3.3 RETRACT/STOW SUNSHADE			
Retract sunshade & stow	PSS control console, sunshield, deployment arm	Manually retract/stow sunshield	Sunshield, deployment arm
		Latch sunshade	Over-center latches
7.3.4 RETRACT/STOW TELESCOPE MECHANISM			
Align telescope in Shuttle bay and retract to stowed position	PSS control console, CCTV	Align telescope in Shuttle bay and retract to stowed position	PSS control console, astronaut, CCTV
7.2 ENGAGE ENTRY LATCHES (TELESCOPE AND IPS)			
Basic sequences			
7.1 CLOSE CONTAMINATION SHIELD			
Basic sequences			
Pressurize telescope internally	PSS control console, pressurization system	Manually pressurize telescope internally	Pressure system
Monitor status/housekeeping telemetry of telescope	PSS control console		
7.12 PURGE FLUID SYSTEMS			
Attach cryogenic coupling to telescope	PSS control console, cryo coupling and arm mechanism	Manually attach cryogenic coupling to telescope	Cryo coupling and swing arm
Drain cryogenic fluid	Vent valves (telescope/storage tank)	Manually open telescope and storage tank vents	Vent valves (telescope, storage tank)
Purge telescope and cryo storage tank	Purge pressure system	Manually operate purge/vent system	Purge pressure system
Drain water storage tanks	PSS control console, water storage tanks, water vent sys.	Manually position water bags for jettison	Water bag jettison system
		Manually energize water bag jettison system	Jettision system
7.9 INSPECT FOR ENTRY			
Basic sequences			

Timeline Comparisons

Figure 3-34 reflects both the baseline and the EVA modes of preparing the SIRTF for operations. The baseline mode requires approximately 2.1 hours, while the EVA mode requires 2.6 hours. The extra time required for the baseline is due to the serial operation of all tasks and verification is performed visually while being performed by the astronaut, slightly reducing the time increment.

A specific issue that could not be scheduled was the time requirement for outgassing of both the telescope and the Shuttle. Any such delay will impact either timeline equally.

The SIRTF is contamination-sensitive; consequently, no EVA should be performed during experiment activity for either baseline or EVA-oriented designs. However, there is a requirement to jettison water collected from the orbiter fuel cell system. During the operational period, scientific investigation must be interrupted for EVA or if water dumping is accomplished remotely. The baseline design option is for water storage which may be prohibitive on a 30-day sortie.

For contingency operations, the experiments will also be interrupted to allow for EVA contingency activities. Such interruptions require the observation end to be pointed away from contamination sources and also for the contamination membrane to be closed.

For the return phase, no timeline was prepared since it was felt that the "preparation for return" will be the reverse of preparation for operations with the omission of the outgassing period.

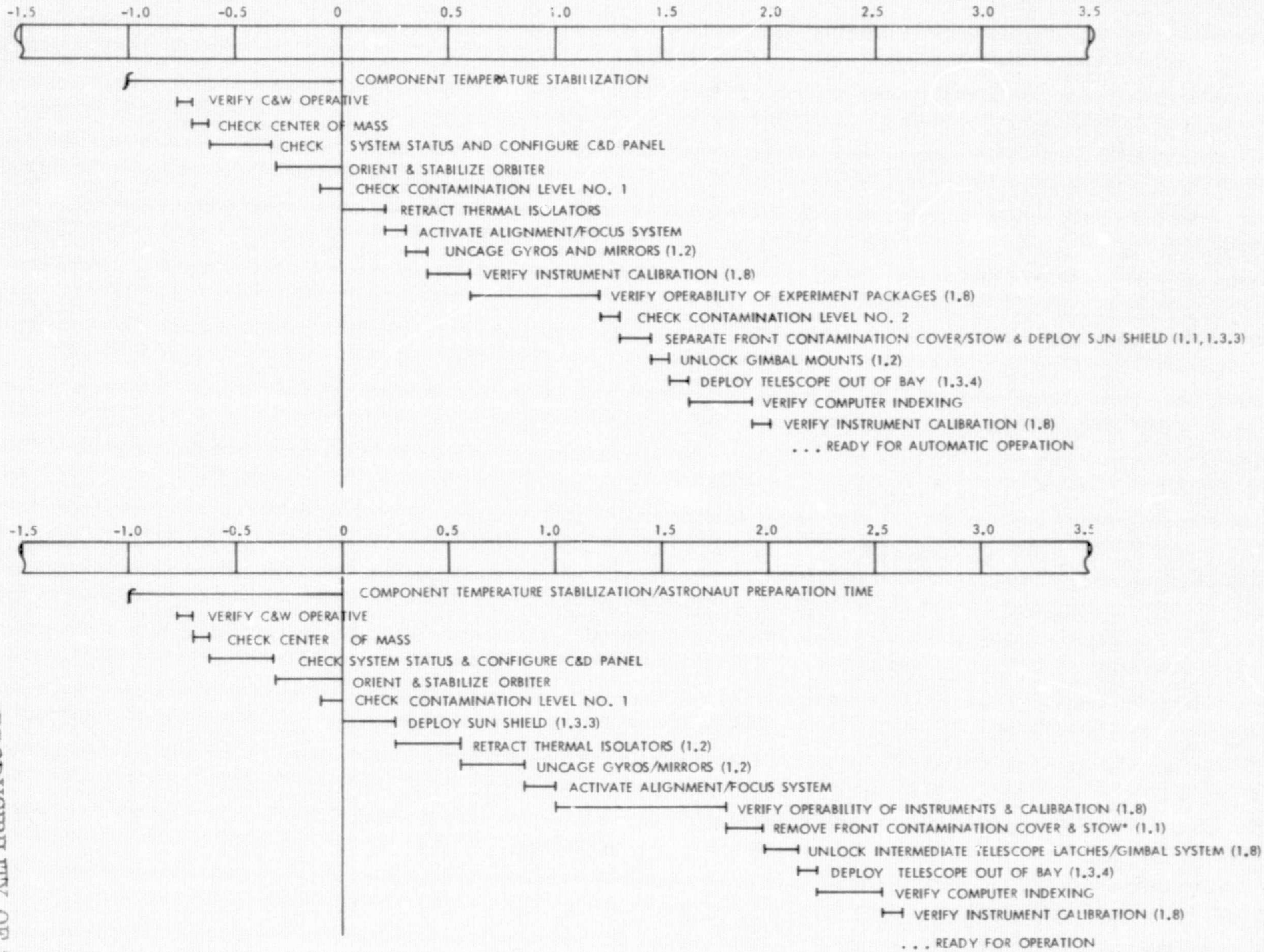


Figure 3-34. SIRTF - Preparation for Operation, Baseline and EVA Modes

3.12 ATMOSPHERIC, MAGNETOSPHERIC AND PLASMAS IN SPACE (AMPS)

The AMPS payload consists of a variety of active and passive instrumentation designed to observe and artificially perturb the space environment and upper atmosphere. Multipurpose controls, displays, and data processing equipment are included to permit effective interaction among on-orbit investigators and experiments. Major assemblies are discussed below; individual sensors and equipment items are identified and defined in the SSPD study.

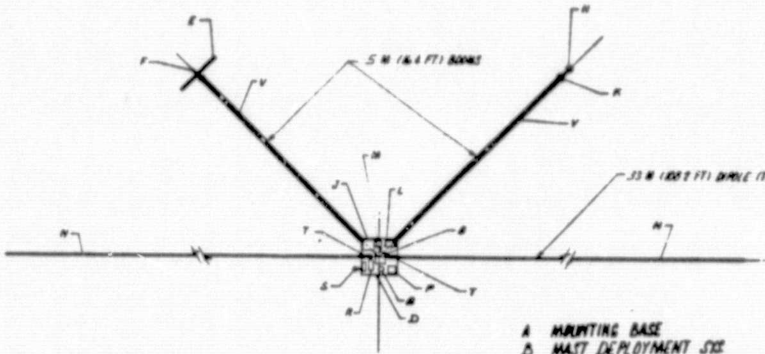
A typical configuration for the AMPS payload might appear as in Figure 3-35; that is, (1) a sortie lab module, (2) a pallet (with at least 3 sections), and (3) scientific equipment. All the controls/display units are located in the Spacelab module, while all the sensors are pallet mounted.

Boom System. The low energy plasmas and small amplitude wave experiments utilize the equipment mounted on two 50 m (164 feet) maneuverable booms. These booms are of the Astromast variety and are identical with the exception of the type of equipment mounted at their ends. Both are attached to the pallet, capable of swiveling at their bases and have swiveling platforms. The diagnostic boom platform supports two 5-m (15 feet) sub-booms of the Astromast-type plus an assortment of particle detectors, TV camera, and data handling equipment. The active boom platform supports energy beam and electrostatic plasma equipment and wake sheath targets.

Gimbaled Accelerator System. This system consists of electron and ion accelerators and a plasma accelerator. The probable configuration of the electron gun is a component-flow cylindrical-geometry Pierce-type accelerator. The proton gun is a multi-aperture electron bombardment ion source and the plasma accelerator is a magnetic-plasma dynamic arc. The gimbaled accelerator system is an integral unit mounted to the pallet approximately in the geometrical center of the Shuttle bay.

Remote Sensing Platform System. The platform, which is mounted on a 2-axis gimbal system, is a circular cylinder 2.42 m (8 feet) in diameter containing a variety of power, data, control, and diagnostic instruments. The gimbal system is controlled by accurate servo-motors providing scanning and stable-viewing capability to the instruments. The cylindrical container/platform maintains a slight positive pressure throughout the launch and entry phases. The platform has a limited X-X axis travel such as to prevent damage to the extended sunshield. This travel angle is ±45 degrees off the platform longitudinal axis.

Deployable Units System. A variety of types and sizes of ejectable devices constitute this system. These devices vary from deployable chemicals and gases to balloons of various configurations. In most cases these units will be spring-ejected from the pallet area and are not intended to be recoverable. The number of units of each type will vary depending on the mission objectives. The direction of launching these units is performed by pointing the Shuttle in that direction for none has a pointing or maneuvering capability.



A MOUNTING BASE
B MAST DEPLOYMENT SYS
C LAUNCH SUPPORT STRUT
D EXPERIMENT MOUNTING PLATFORM
E 1 METER LOOP
F SHORT WAVELENGTH ELECTRIC DIPOLES
G TRIAXIAL SEARCH COILS
H RUBIDIUM MAGNETOMETER
J TRIAXIAL HEMISPHERICAL ANALYZER
K TRIAXIAL FLUXGATE MAGNETOMETER
L PLANAR ION TRAP OR NEUTRAL MASS SPECTROMETER
M ALIGNMENT TV CAMERA
N LONG ELECTRIC DIPOLE FOR AC & DC
O POWER SUPPLY & DATA SYS
P PLANAR ELECTRON TRAP
Q CYLINDRICAL PROBE
R ION MASS SPECTROMETER
S SPHERICAL ION PROBE
T STEM ACTUATOR
U DEPLOYED MAST
V 5 METER BOOMS (16.4 FT)

ITEM	FUNCTION	SYSTEM
1	DEPLOY BALLOONS	ACTUATE SERVO RELEASE - SPRING LOADED MECHANISMS
2	DEPLOY SATELLITES	SERVO OPERATED LATCHES - RMS DEPLOYMENT SYSTEM
3	EXTEND 50 M SENSOR SUPPORT BOOM "A"	ACTUATE SERVO MECHANISM FOR ELEVATION ROTATION & EXTENSION
4	EXTEND 50 M SENSOR SUPPORT BOOM "B"	SAME AS ITEM 3
5	EXTEND 330 M DIPOLE ANTENNAS	SERVO ACTUATED MECHANISM FOR BOOM EXTENSION
6	ACTUATE LIDAR EXPERIMENT	SERVO OPERATED LATCHES, DETENTS, SPRING LOADED HINGES
7	ACTIVATE ION ACCEL EXPERIMENT	ACTUATE SERVO LATCHES, DETENTS & POINTING MECHANISM
8	RELEASE SENSOR PLATFORM	ACTIVATE MECHANISM FOR GIMBAL RELEASE, ELEVATION & ROTATION
9	RELEASE BARIUM CANNISTERS	ACTUATE RELEASE - SPRING LOADED MECHANISM
10	RETRACT COVER & EXTEND SUNSHADE	SERVO ACTUATED MECHANISM TO RETRACT COVER & EXTEND SUNSHADE

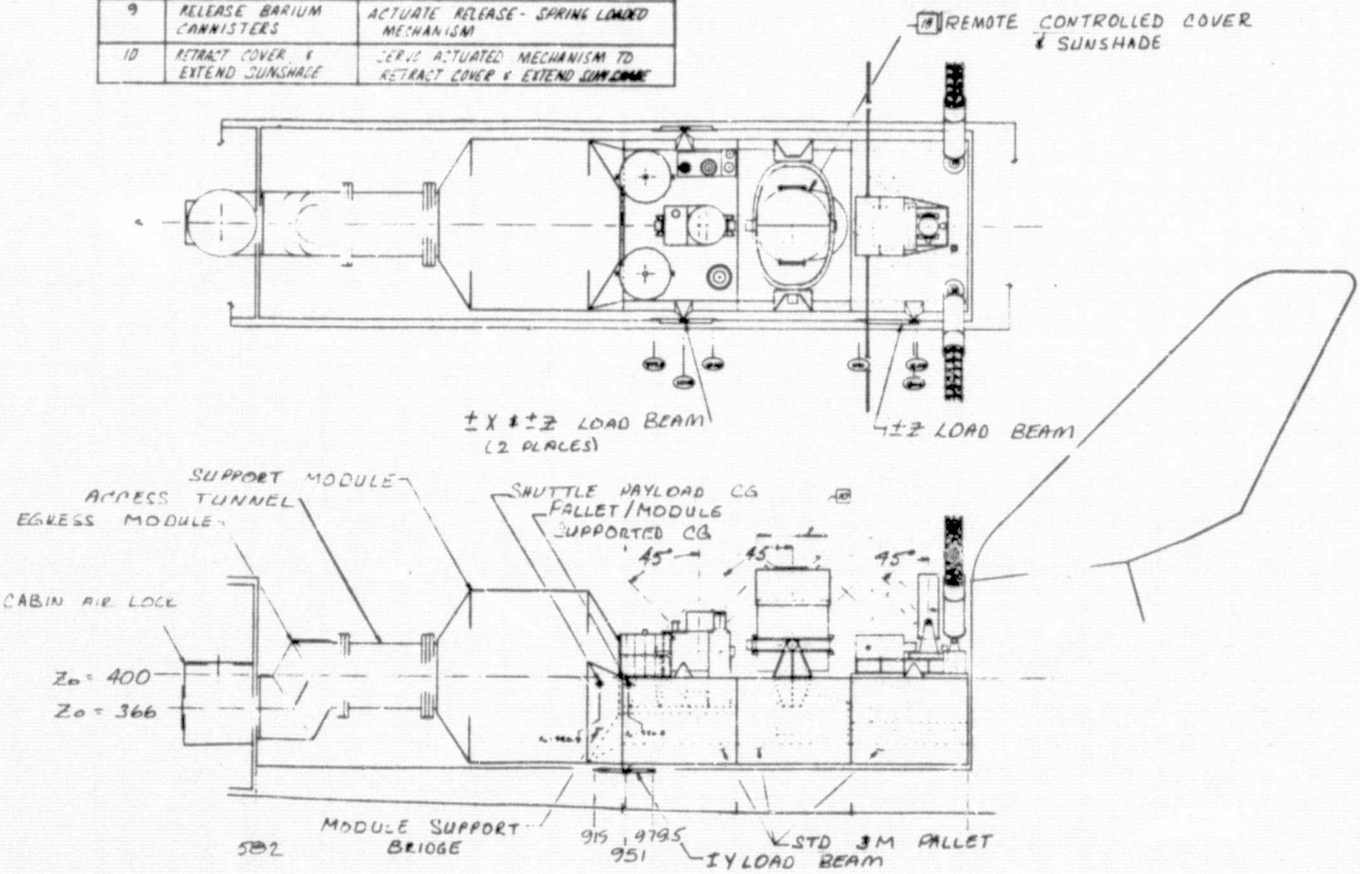


Figure 3-35. Baseline AMPS Payload

Transmitter/Coupler System. The transmitter is a high-powered radio transmitter using modulated long sounding antenna elements of up to 303 m (1000 feet) each in length. The transmitter, coupler, and antennas are integrated into a single unit mounted on the pallet. Antenna elements are deployed in both the plus and minus y axis of the shuttle. The system is operated at such appropriate times as not to interfere with the other experiments both physically and energy-wise.

Satellite System. Two subsatellites approximately 1 m (3.3 ft) in diameter by 1.5 m (5 ft) in length are mounted on separate pedestals on the pallet. The subsatellites are checked out prior to launch and are controlled from the Shuttle during the experiment period after which they are recovered by the Shuttle and returned for ground refurbishment. During the experiment phase, the data collected by the satellites is transmitted back to the Shuttle data management system.

Laser System. The laser system used in conjunction with equipment items of several of the other systems is also mounted to the Spacelab pallet. The system mounting consists of a circular cylinder, containing the laser transmitter/receiver, attached to a gimbaling unit mounted directly to the pallet. During launch and entry, the cylindrical container maintains a slight positive pressure such as to prevent contamination of the lens.

3.12.1 Baseline Payload Operations Definition

The AMPS payload is a complex integration of a variety of sensors and supporting devices. Consequently, it was felt that the most probable automated sequence for deployment would be by generic or grouped sensors. In addition, to satisfactorily perform the AMPS mission many of the sensors are operated simultaneously to take advantage of the synergistic effect and obtain backup information.

The operation of this payload will ideally require at least three experiment crew members, one in each of the major investigative areas: (1) plasma physics and environmental perturbations, (2) atmosphere science, and (3) magnetospheric and auroral phenomena. In addition, cross-training will be required for each of the experiment crew in order to retain the minimum crew.

Being a collection of a large mix of sensors and since most of the sensors operate simultaneously in many of the experiments, it was felt that no experiment should be started until all items were deployed, checked out and activated. Therefore, since the baseline documentation categorizes the sensors and supporting items into various systems, "preparation for operation" has been analyzed from the viewpoint of deploying those most likely to be either hazardous or require some time to separate/translate from the Shuttle or immediate Shuttle vicinity.

The pallet mounted equipment deployment in the baseline mode requires approximately 3.5 hours. Many of the deployment sequences are performed in parallel with each other with exception of those which require the astronaut's complete attention (i.e., deployable units system, deployable satellite system and the boom system). However, when some of these systems are nearly deployed, the next system sequence may be started (reference Figure 3-37 Preparation for Operation - Baseline Mode). The more condensed systems

(i.e., lidar, gimbaled accelerator and remote sensing systems) may be deployed in a totally parallel sequence.

Control and Display Operational Readiness Check. Following the sequence of events establishing the Shuttle on orbit, the astro-scientist crew will transfer from their normal Shuttle launch position to the Spacelab module. At this time, a post-insertial/pre-operation checkout will be performed on each console, control panel, and supporting unit. It is presently estimated that approximately 10 display units will be provided by the Spacelab, with up to 11 additional units provided by the experiment. In addition, approximately 11t experiment-provided control units will also be included.

The plan is for one astronaut-scientist to read the checklist while the other two are strategically positioned to verify switch positions or meter readings. Such a checkout, based on astronaut-scientist familiarity with equipment and past experience gained from similar earth-bound activity and Skylab Missions should not exceed the 0.50 hours indicated in the timeline.

Having verified that all switches are properly positioned and selected meters and displays are within specification, the experiment crew persons are now available to begin deployment and preparation of the experiment pallet-mounted items.

Deployable Units - AP600. Checkout Deployment System/Setup Balloons - A crewman will begin to set up the deployable units panel to check out the various units consisting of balloons and various sizes of barium canisters. This consists of circuit continuity checks of the entire system, and arming of the ballon deployment unit.

While the continuity check is being performed, a second crewman will be readying the remote manipulator so as to view the deployable units for any visual indications of a contingency. After verifying the readiness of the system the Shuttle attitude will be positioned favorably to launch the balloons. Two balloons, one a cylindrical configuration and the other spherical, will be launched at the proper time. Automatic sequencing will inflate the balloons which continue beyond the wake influence of the Shuttle. Orientation of the Shuttle and launching of the balloons will take approximately 0.2 hour.

Subsequent launching of the barium canisters will be performed in a similar manner as the balloons during a later phase of the mission; therefore, no further discussion of these units will be given.

Deployable Satellites - AP700. The discussion under this heading is applicable only to a single subsatellite; the same is applicable to any subsequent satellite deployment. Checkout of a subsatellite may be started by the third crewman simultaneously with the deployable units. The checkout is primarily a one person activity consisting of a subsystem remote check of the subsatellite and its sensor components prior to launch. Each satellite is an autonomous unit in its operational state; therefore, it requires a rather thorough pre-insertion checkout. It is anticipated that as much as 0.5 hours will be required to satisfy operational readiness for each unit.

Following the satisfactory completion of the satellite checkout, a visual inspection will be made via a television camera mounted on the remote manipulator or by other remotely mounted TV cameras capable of observing critical portions of the satellite. It is anticipated that 0.1 hour is adequate.

Conservatively 0.05 hour is alloted to the engagement of the remote manipulator to an appropriate fitting on the satellite and for the compliance with the remote command for the boost locks to unlatch. Verification of both these actions being completed satisfactorily is by talk-back devices and TV.

Finally, the remote manipulator disengages the satellite from its tie-down interface and articulates outward to its maximum position away from the Shuttle where it releases the satellite after receiving a verification signal of operational activity (i.e., stability of satellite using its own stabilization system). The Shuttle then translates away from the satellite sufficiently so that the satellite's own propulsion system may be activated.

Boom System - AP500. The boom system, which may be characterized as the most mechanically complex system of the payload, is deployed next. Each of the two booms has the capability of being extended some 50 meters (164 ft) beyond the pallet interface via an Astromast-type deployment mechanism loaded within a canister.

The first task is to program all appropriate switches on the C&D panels to the proper position. Having done this, a command is then sent to unlatch Boom A from its boost position and to erect the platform, Boom A, and canister to a vertical position (with reference to the pallet).

The next task is to orient the sensor platform, mounted on Boom A, such that the other devices can be safely deployed and monitored. This is accomplished by commanding the platform to unlatch and position itself parallel to the pallet. This consists of unlatching two 5-meter (16.4-ft) Astromast-type booms. At the end of one of the 5-meter booms is a loop antenna that is affixed to a spherical ballon, and deployment occurs by inflating the balloon. While the Astromast-type booms are being deployed, the 33-meter dipole (108-ft) is also energized and allowed to be deployed. During all these deployments, close attention must be given to assure smooth operation and adequate clearance of all equipment.

The deployment of the dual 5-meter booms and 1-meter antenna should not exceed an estimated 0.05 hour and the deployment of the 33-meter dipole antennas 0.15 hour.

After having successfully deployed all the devices on Boom A, 0.25 hour is alloted to verify that there is continuity electrically and that all the scientific equipment is functioning. This is done to verify the system prior to deploying the platform to its 50-meter limit. The 50-meter boom is given 30 minutes to drive out the platform at a rate of 5.5 feet per minute. This rate is considered to be slow enough not to damage the large deployed units. It is noted that 1.25 hours are required to prepare and deploy Boom A to its operational configuration.

During the deployment of Boom A the second crewman can begin preparing Boom B by programming switches on the C&D panels to the proper position and commanding the unlatching of Boom B and erecting it perpendicular to the pallet. Time alloted is 0.1 hour. Once this has occurred, the platform on the free end of Boom B is unlatched and gimbaled to the position where it is parallel with the pallet.

Finally, having successfully performed all commands the boom is then tilted per experiment requirements and driven out the 50-meter length. The extension time is similar to Boom A.

The total time to prepare the boom system is scheduled for 1.4 hours allowing some overlap time for deploying the booms.

Transmitter/Coupler System - AP400. The automated "preparation for operation" of this equipment consists of configuring the control panel(s) as required; verifying that there are no interferences for the dipole antennas and then commanding each antenna to extend the 330 meters (1083 feet) and monitoring same and finally to check out the transmitter equipment.

The total time to prepare the equipment is 0.65 hour of which the majority is in deploying the 330-meter dipole antennas. Consequently, the checkout can be performed simultaneously with the boom system (AP500).

Lidar System - AP200. The lidar system is an integrated unit mounted on a gimbal system. The initial task is to configure the control/display panel for operation and to unlatch and stow the contamination cover. The time to perform this task is 0.1 hour. Completing this step, the experiment crewman performs a checkout of the lidar system.

Gimbaled Accelerator System - AP300. The gimbaled accelerator system, like the lidar system, is a simple arrangement with respect to preparation for operational readiness. There are two major tasks: task one consists of configuring the control and display panel switches for operation; to unlatch the gimbal locks, and to position the unit to its operational position; task 2 is to perform an equipment checkout. The time for the two tasks is 0.15 hour.

Remote Sensing Platform - AP100. The remote sensing platform consists of a relatively large pressurized canister mounted on a dual-axis gimbal mount. The following four major activities have been identified to prepare the equipment for operation with a total performance time of 0.65 hour.

1. Configure the control/display and simultaneously being a depressurization of the canister

2. Unlatch, remove, and stow contamination cover

3. Extend sunshade to its operational position, unlatch gimbal lock

4. Perform equipment checkout on each item mounted within the canister

Summary. The above description summarizes the generic tasks and times to get the AMPS payload ready for normal operation. It is noted that only one subsatellite (AP700) was launched early in the mission. The second subsatellite can be launched in a similar manner anytime during the normal mission; however, great care must be given to the fact that large antennas and booms (AP400 and AP500) are deployed and additional time may be required to translate the Shuttle away from the launched subsattellite prior to its activation in free flight.

Note that both balloons (AP600) were deployed early. The reason being to allow greater separation from the Shuttle's perturbation wake as early in the mission as possible allowing greater utilization of the subsattelites.

No schedule has been prepared regarding the barium canister deployment (AP006). However, the system was checked in early phase of the pre-readiness check and only requires coordination with the ground to eject the barium canister. It is estimated that no more than 0.2 hours are required to position the Shuttle for proper orientation when ejecting the barium units.

From this discussion and accompaying timeline it can be concluded that the entire "preparation for operation" check will take approximately 3.5 hours utilizing the services of a minimum of three astronauts thoroughly familiar with the experiment operations, control, and procedure. Many tasks are performed concurrently. Those which are of a sensitive nature are all performed on a solo basis (AP700 satellite deployment, AP500 boom deployment, and AP400 dipole antenna deployment). More specifically these tasks are individually performed until it is seen that no further obstructions will materialize.

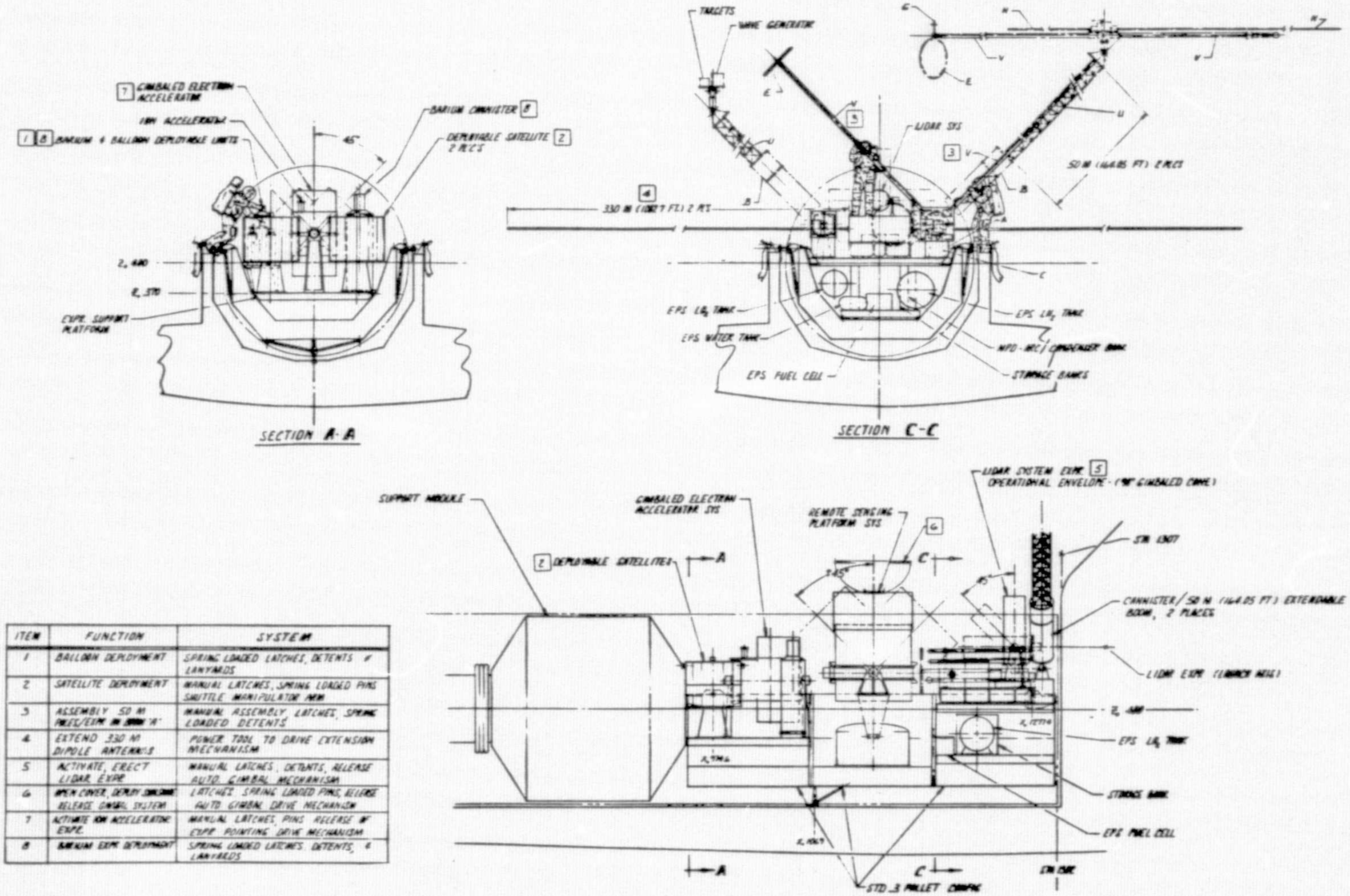
3.12.2 EVA Applications

The major EVA effort is exerted during both the preparation for operation and the preparation for entry. Since most of the equipment is so large or generates large amounts of radiation, the normal mission experiment operations are conducted from the control and display area; although some EVA will be required. Use of EVA has also allowed simplification of some equipment such as replacing deployable booms with stowed tubular masts. The major benefit derived from EVA is simplification of Shuttle to payload interfaces. Figure 3-36 illustrates the EVA-to-payload interfaces.

Preparation of the AMPS payload via EVA does not substantially reduce the basic complexity of deployment of the large quantity of equipment items. Therefore, the same approach was used to prepare the payload for operation, deployment by generic or grouped sensors.

The preparation of this payload was based on utilizing at a minimum a crew of two performing the EVA functions while a third is in the Spacelab module supporting the others. Two crewmen in the Spacelab module could function more effectively; however, the timeline is based on three people total.

As in the automated discussion, the same sequence of equipment deployment is used in the EVA mode. That is, deployment of the most sensitive/complex units first (i.e., subsatellites and balloons, then large deployable structures).



ITEM	FUNCTION	SYSTEM
1	BALLOON DEPLOYMENT	SPRING LOADED LATCHES, DETENTS & LANYARDS
2	SATELLITE DEPLOYMENT	MANUAL LATCHES, SPRING LOADED PINS SHUTTLE MANIPULATOR ARM
3	ASSEMBLY 50 M POLES/EXPR IN [illegible] 'A'	MANUAL ASSEMBLY, LATCHES, SPRING LOADED DETENTS
4	EXTEND 330 M DIPOLE ANTENNAS	POWER TOOL TO DRIVE EXTENSION MECHANISM
5	ACTIVATE, ERECT LIDAR EXPR	MANUAL LATCHES, DETENTS, RELEASE AUTO. GIMBAL MECHANISM
6	OPEN COVER, DEPLOY [illegible] RELEASE GIMBAL SYSTEM	LATCHES. SPRING LOADED PINS, RELEASE AUTO GIMBAL DRIVE MECHANISM
7	ACTIVATE ION ACCELERATOR EXPR.	MANUAL LATCHES, PINS. RELEASE OF EXPR POINTING DRIVE MECHANISM
8	BARIUM EXPR DEPLOYMENT	SPRING LOADED LATCHES. DETENTS, & LANYARDS

Figure 3-36. AMPS Payload EVA Operations

Space Division
Rockwell International

A review of the timeline shows that many of the less complex installations can be performed simultaneously. The boom system and the satellite systems are not compatible for simultaneous deployment. By their very nature the satellites once released are free to move about and not having a total field of view of both satellite and the deployed antennas, it can become a sensitive situation. The total time required for deployment via EVA is approximately 4.6 hours.

Control and Display Operational Readiness Check. Once the Shuttle has been established on orbit, an astronaut-scientist will transfer to the Spacelab module and perform a status check of the control and display equipment. It is anticipated that the 10 display units provided by the sortie lab and the 11 additional experiment-unique displays will remain. However, of the 115 experiment-provided control units (with integrated talkbacks) approximately 20 percent will be deleted due to the manual EVA-performed functions. The time allotted (0.5 hour) is based on a single astronaut performing a check of the reduced number of C&D units.

Having verified that all switches are properly positioned and that selected meters and displays are within specification, the EVA crewmen are now permitted to begin preparation and deployment of the experiment pallet-mounted items.

It is noted that during the C&D checkout, the EVA crew have already prepared themselves for EVA activity (pre-breathing) and have exited the pressurized volume for the pallet.

Deployable Units - AP600. A crewman positions himself in front of the deployable units panel and configures it per procedure.

The EVA crewman performs a visual inspection for any damage or obvious defects of the balloon canisters and the seven multi-sized barium canisters. Following a successful inspection the packaged balloons are deployed into space. The balloon deployment mechanism is a simple mechanical device which is spring-loaded. It requires only that the astronaut pull a lever. As the balloon canister is deployed, a timer attached to the canister sets off the inflating mechanism at the proper time. Both balloons are deployed within a few minutes of each other, but are positioned such that they translate away from the Shuttle and away from each other.

It is noted that the barium canisters are not launched during this phase (preparation for operation) but rather at a later time. Balloon deployment should not exceed 0.30 hour. Barium deployment consists of releasing a spring-loaded device which spins the barium canister and releases it. The only difference between the balloon release and barium release is the spinup of the barium to prevent tumbling and a possibility of discharging the barium back toward the Shuttle.

Deployable Satellite System - AP700. The discussion herein applies only to deployment of a single satellite. The second satellite follows a similar sequence of events but a slightly longer deployment period is required due to the need for greater caution when the large appendages are deployed.

Checkout of the subsatellite can be started in conjunction with an earlier task (i.e., deployable units--inspect payloads and launch balloons). This is due to the fact that a single astronaut will be performing all the functional checks at the C&D panels. Approximately 0.5 hour are required to verify the satellite subsystems and experiment equipment items.

As soon as the EVA crew has completed all the tasks at the deployable units station (i.e., securing the areas from where the balloons were launched), they then translate over to the deployable satellite station and proceed to perform a physical inspection of the selected satellite. The translation is included in the inspection time.

Having found no discrepancies one EVA astronaut provides vernier guidance to the remote manipulator during manipulator-to-satellite attachment. The other astronaut then translates to the satellite latching mechanism in preparation for deployment.

Upon disengagement of the satellite from its pallet mount, both EVA astronauts help guide the unit and dampen any induced oscillations. The manipulator is operated from the RMS station temporarily using a Shuttle crewman. The manipulator is then extended such that the satellite is the maximum distance from any point of the Shuttle. The manipulator releases the satellite and the Shuttle translates down and forward of the satellite which is remotely commanded to depart from the Shuttle vicinity under its own power.

The comparison of performing this task remotely versus EVA is 0.85 and 0.90 hour. The times are quite similar although one might expect a shorter remote deployment time. However, performing the task remotely requires the events to be performed serially due to a lack of direct visual cues and electronic access to the pallet-mounted equipment.

Boom System - AP500. The boom system deployed even via EVA remains one of the most complex of activities. Each of the two 50-meter booms retain the astromast design and the requirement for articulation in two planes, remaining remotely deployable and maneuverable. The initial task in deployment requires configuration of the control/display panel switches.

Following the switch positioning task at the C&D panels, both of the EVA astronauts proceed to the sensor platform mounted at the end of Boom A. The astronauts retrieve two matched sections of a 5-m tubular pole, assemble it via the quick disconnect-type connector and one of the astronauts inserts the assembled unit into its proper operational fitting. This same sequence is followed assembling a second deployed 5-m experiment boom. All electrical connections are then made (0.3 hour).

When the astronaut has completed the above tasks, he removes the contamination covers from appropriate instruments and unlatches all mechanisms as required plus unlatches the gimbal platform (0.25 hour). The other astronaut begins to unlatch the retention mechanism on the Boom A canister.

Rather than deploy the 50-m Boom with a faulty instrument, an in-situ check is performed to verify that all the sensors are functioning. This permits corrective action to be taken or at least to perform a visual inspection for any contingencies. Assuming no problems, the 50-m Boom is then remotely deployed at a rate of 5 to 6 feet per minute requiring 0.50 hour for full deployment. Approximately 0.25 hour into the deployment phase of Boom A another remotely performed function is activated to drive out two 33-meter dipole antennas mounted on the sides of the experiment platform. At this time the platform is well clear of any Shuttle appendages and the dipoles can be freely deployed.

As Boom is being deployed, the astronauts translate to Boom B where the contamination-sensitive sensors (targets and calibration light) have their covers removed and stowed and the gimbal platform unlatched. In conjunction with the above task the other astronaut begins to unlatch Boom B latching mechanisms. When all latching mechanisms have been released (Boom B and platform), Boom B is then extended in the same manner and at the same rate as Boom A (0.50 hour).

The overall deployment time of the boom system performed remotely is 1.4 hours versus 1.9 hours per EVA. Some of the changes to the remote system which would substantially affect overall cost is that the two 5-meter booms were replaced by hollow 5-meter shafts removing the requirement for powered drive systems, commands, limit switches, etc. The hollow shafts are stowed on the pallet and mounted on Boom A's platforms manually.

In both situations (automated and EVA) all the dipole antennas are of the stem type and self-contained motor driven. The motorized units were selected due to the EVA activity described herein (i.e., all astronaut activity being performed at the pallet level), and because of various interferences if deployed at pallet level.

Transmitter/Coupler System - AP400. Preparation for operation is identical to the automated procedure with the exception that the contamination cover is removed manually and stowed. The difference in times 0.75 versus 0.6 hours (EVA versus baseline) is totally due to the manual task. The interface between the antenna control mechanism and the C&D panel is substantially simplified with the removal of motor drives, limit switches, talkbacks, wires, and the like. Integrated motorized devices are favored for antenna deployment since they exist as off-the-shelf items and because deployment of 330 meters (1083 ft) traveling at 1 meter in 6.6 seconds (6 inches/sec) requires a minimum time of 33 minutes. The stem device (suggested stem antenna, Model A-463) studied has a self-contained extend/retract motor drive. As the antenna is deploying there is little if anything an astronaut can do except observe. Rather than have the astronaut standby, he can traverse to the next system and begin to deploy it.

Lidar System - AP200. The lidar system is basically a laser unit integrated into a gimbaled contamination container. The astronaut activities will be to remove contamination covers, orient the lidar from its launch position to its normal operating position, and to remove gimbal latching devices. This is a one man operation which should not exceed 0.1 hour. The major simplification of interfaces is the elimination of a drive motor, limit switches, wires and panel talkbacks and controls.

Gimbal Accelerator System - AP300. The gimbal accelerator system is quite similar to the lidar system in that the EVA task only consists of removing and stowing a contamination cover and removal of gimbal latches requiring a maximum time of 0.1 hour. The simplification of this system is equivalent to the discussion above for lidar system.

Remote Sensing Platform - AP100. Preparing the remote sensing platform for operation requires that an astronaut verify that the canister pressure has vented down to the ambient conditions; if not then, he will open a dedicated vent valve and ensure evacuation (0.05 hour).

The astronaut circulates about the container and unlatches each of the mechanical devices. He then removes the contamination cover and manipulates it to the second astronaut who secures it to a designated fixture. With the cover stowed the astronauts position the sunshield by manually extending it to its limit.

Final EVA activity consists of unlocking the gimbal mount. With both astronauts working, each unlatches two of the mechanisms closest to his station. The majority of the the time increase is the removal of the contamination cover as the single astronaut circulates about the canister removing the cover latches. The EVA activity is increased by 0.10 hour over the baseline mode.

3.12.3 Operations Analysis

Operations Cycle

The first-level operation cycle block diagram for the AMPS is shown in Figure 3-2. The figure shows a single continuous flow which is applicable for either baseline or EVA operations. Many of the tasks will be the same, specifically, remote operation will be required for the general operations and EVA will be primarily used for setup and stowage of experiment equipment.

Sequence Comparisons

Many functions are the same in both the baseline and EVA modes. Specifically, preparation for operations follows the same basic pattern. EVA is utilized for arming and unlatching the deployable units, and EVA is utilized for inspection and release of the deployable satellites.

Several of the experiment systems can be configured to depend heavily upon EVA. These are (1) boom system, (2) lidar system, (3) gimbaled accelerator system, and (4) remote sensing platform system. The lidar, gimbaled accelerator, and remote sensing systems primarily use EVA to set up the various equipment. These tasks consist of depressurization of the contamination containers, removal of contamination shields, unlatching of gimbal mounts, and visual inspections. EVA is also applicable to perform the Preparation for Entry sequence. Table 3-13 presents the task sequences.

The boom system benefits the most from EVA. For example, EVA can be used to erect light-weight booms which in the baseline requires a deployable astromast boom. Sophisticated antenna deployment may be performed via EVA eliminating sophisticated deployment systems (balloon inflated circular antenna).

Table 3-13.
ATMOSPHERIC, MAGNETOSPHERIC AND PLASMAS IN SPACE
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
1. PRE-OPERATIONS			
Activate primary bus		Activate primary bus	
		Proceed to pallet work area	Handholds, foot restraints, and work stations
DEPLOYABLE SATELLITES			
1.10 VISUAL INSPECTION (Deployable Satellites)			
Basic sequences			
1.8 TEST AND CHECKOUT			
Basic sequences			
1.4 ENGAGE RMS			
Engage RMS to Satellite	RMS control panel	Assist engagement of RMS to satellite	RMS control panel, RMS end effector
1.2 DISENGAGE BOOST LOCKS			
Basic sequences			
2. EXPERIMENT OPERATIONS			
2.1 LAUNCH SUBSATELLITES			
Position satellite to normal launch position, disengage RMS	RMS and RMS control console	Position satellite to normal launch position disengage RMS	RMS and RMS control console
Translate orbiter from satellite	Orbiter	Translate Orbiter from satellite	Orbiter
BOOM SYSTEM			
1.3 EXTEND INSTRUMENT BOOMS			
Disengage boom/boost locks	C&D panel and boom boost latches	Inspect experiment equipment on boom A platform	Visual inspection
Erect boom A vertically	C&D panel and boom drive system	Assemble two 5-m pole-booms to boom A platform	Disassembled pole booms, fittings and connectors
Deploy two 5-m booms on platform	C&D panel and 5-m boom drive system	Manually unlatch boom A boost locks	Boom A boost locks
Deploy 33-m dipole antennas	C&D panel and 33-m antenna drive system	Erect boom A to vertical position	C&D panel
Deploy loop antenna	C&D panel antenna deployment system	Deploy 33-m dipole antenna	Handhold drive unit and experiment equipment
Verify continuity of boom(s) & experiment equipment	C&D panels and experiment equipment	Perform continuity check of boom A experiment equipment	C&D panels and experiment equipment
Deploy boom A to full length	C&D panel and boom A deployment system	Deploy boom A fully	C&D panel and boom A deployment system

Table 3-13. (continued)

ATMOSPHERIC, MAGNETOSPHERIC AND PLASMAS IN SPACE

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts
Unlatch boom B	C&D panel and boom B latches	Unlatch boom B manually	Boom B boost latches
Erect boom B vertically	C&D panel and boom B drive system	Erect boom B vertically	C&D panel and boom B deployment system
Verify continuity of boom & experiment equipment	C&D panel and experiment equipment	Verify continuity of experiment equipment on boom B	C&D panel and experiment equipment
Deploy boom B fully	C&D panel & boom B drive sys.	Deploy boom B fully	C&D panel & boom B deployment system
TRANSMITTER/COUPLER SYSTEM			
1.3 EXTEND ANTENNAS			
Deploy 330-m dipole antennas	C&D panel and antenna drive system	Deploy 330-m dipole antennas	C&D panel and antenna drive system
Verify transmitter/coupler system continuity	C&D panel and experiment equipment	Verify transmitter/coupler system continuity	C&D panel and experiment equipment
1.10 VISUAL INSPECTION			
Basic sequences		Basic sequences	
LIDAR SYSTEM			
1.1 REMOVE CONTAMINATION SHIELD			
Depressurize contamination container	C&D panels and pressure venting system	Manually verify and/or depressurize contamination container	Vent system on container
Basic sequences			
1.10 VISUAL INSPECTION			
Basic sequences			
1.2 DISENGAGE BOOST LOCKS (GIMBAL MOUNTS)			
Basic sequences			
1.8 TEST AND CHECKOUT			
Basic sequences			
GIMBALED ACCELERATOR SYSTEM			
1.1 REMOVE CONTAMINATION SHIELD			
Basic sequences			
1.2 DISENGAGE BOOST LOCKS (GIMBAL MOUNTS)			
Basic sequences			
1.8 TEST AND CHECKOUT			
Basic sequences			

Table 3-13. (continued)

ATMOSPHERIC, MAGNETOSPHERIC, AND PLASMAS IN SPACE

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequences	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
1.10 VISUAL INSPECTION			
Basic sequences			
REMOTE SENSING PLATFORM			
1.1 REMOVE CONTAMINATION SHIELD			
Depressurize the RSP container	C&D panel, vent system	Manually vent RSP container	Vent system
Unlatch and remove contamination cover and stow	C&D panel, container locks, retraction mechanism	Manually unlatch, remove and stow cover	Cover latches, stowage mechanism
Deploy sunshield	Sunshield, drive mechanism C&D panel	Manually deploy sunshield	Sunshield
1.10 VISUAL INSPECTION (Platform and Experiment Equipment)			
Basic sequences			
1.2 DISENGAGE BOOST LOCKS (Platform Gimbal)			
Basic sequences			
1.8 TEST AND CHECKOUT			
Basic sequences			
7. PREPARE FOR RETURN			
Inverse of 1. Pre-Operation		Inverse of 1. Pre-Operation	

No specific sequence of operations is defined for several of the EVA applications. Those areas not discussed along with the reason for omission are listed below.

Operation Area	Sequence Omission
2.0 Experiment Operations	In both the baseline and EVA modes, EVA is not required or planned due to the nature of the experiment equipment.
3.0 Contingency Operations	Dependent on the type of contingency. Each must be handled on a real time basis. Specific contingency problems discussed in separate section.
4.0 Separate Spacecraft	Not applicable for sortie missions
5.0 Docking Operations	Not applicable for sortie missions
6.0 Planned Maintenance	Other than specimen or film retrieval no planned maintenance is required. For those activities requiring maintenance refer to Pre-Operations section
7.0 Prepare for Return	Inverse process of Pre-Operations. The exception is for non-recoverable items, their launching devices are secured for entry.

Timeline Comparisons

Figures 3-37, 3-38, and 3-39 reflect AMPS baseline - Preparation for Operation, EVA - Preparation for Operation, and EVA - Preparation for Return. No timeline was prepared for the operations phase since all the equipment is deployed early in the mission and there is no direct requirement to service the units as such.

Included is a timeline for entry preparation via EVA but not for the baseline. The baseline is a direct reversal of the deployment.

In the preparation for operations phase, a similar pattern was used for both baseline and EVA modes to deploy as much of the payload as early as practical yet within the experiment program. The approach used was to deploy items with the highest probability of interference first (subsatellites and 50-meter booms) down to the items of least sophistication with respect to deployment.

The EVA time exceeds the baseline by approximately one hour. Nearly every sensor system was affected in the EVA mode with the greatest increase of time in the boom system. This was due primarily to manually installing the 5-meter booms versus deployment of the 5-meter Astromasts.

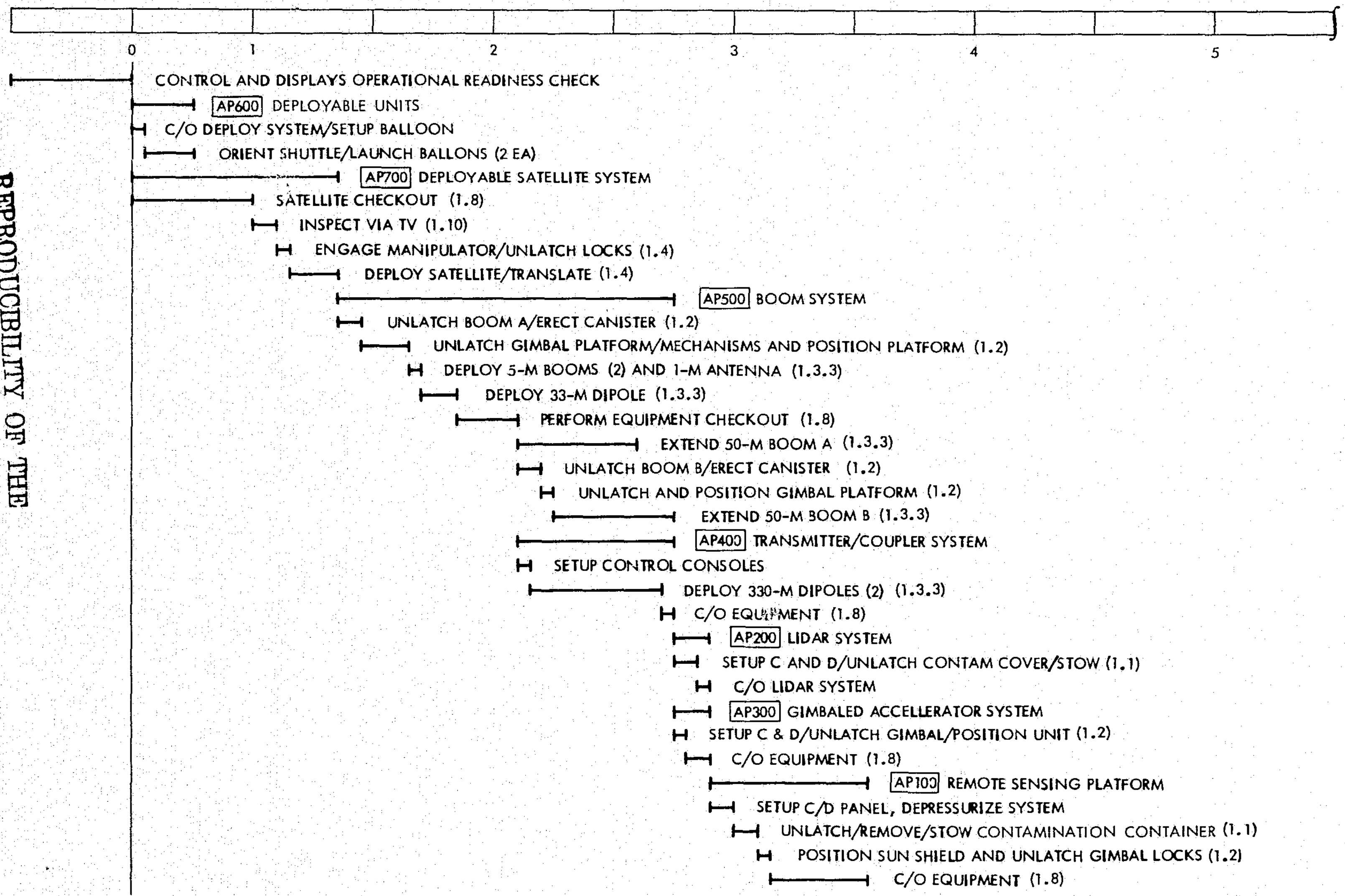


Figure 3-37. AMPS - Preparation for Operation, Baseline Mode

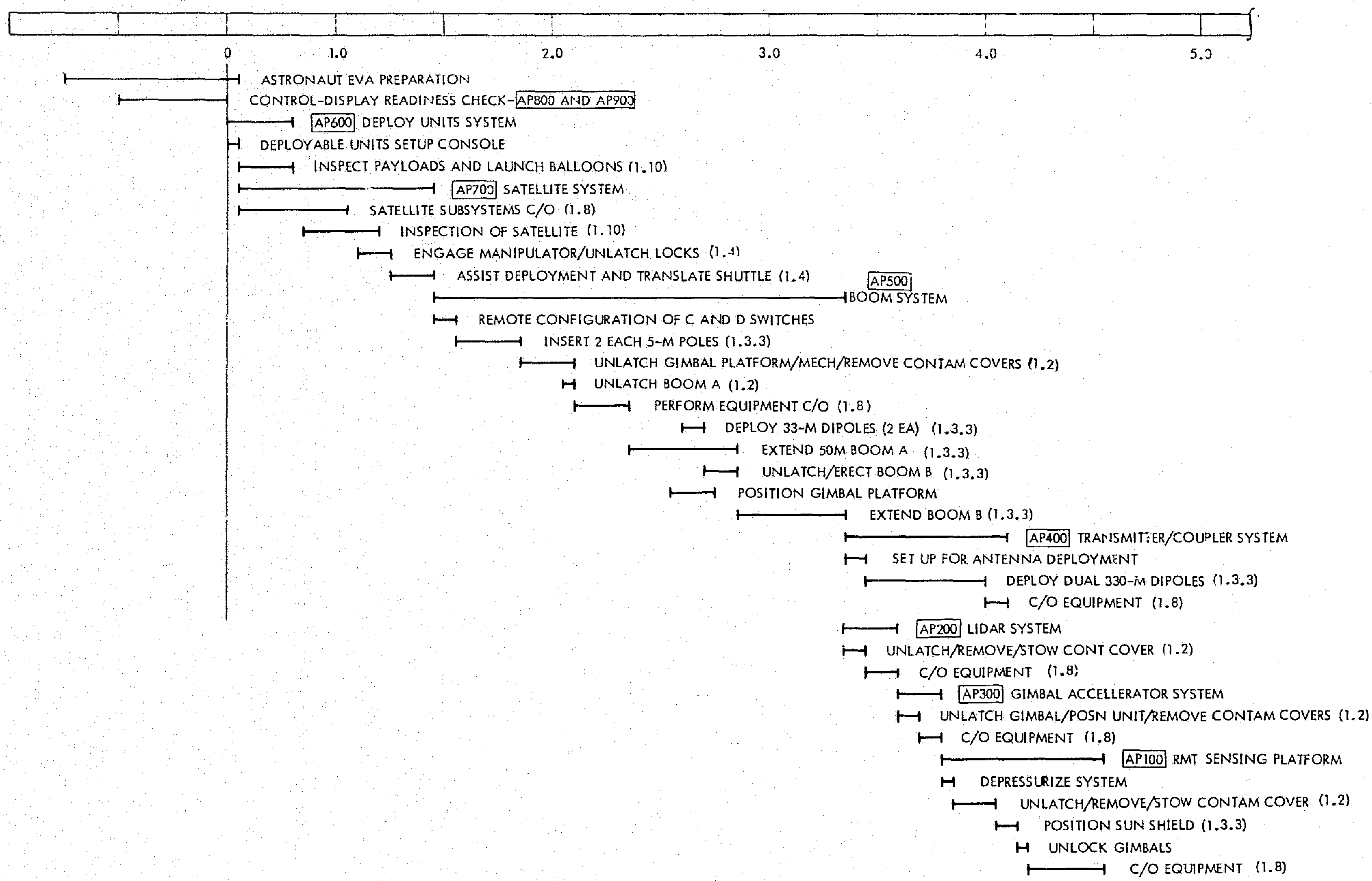


Figure 3-38. AMPS - Preparation for Operation, EVA Mode

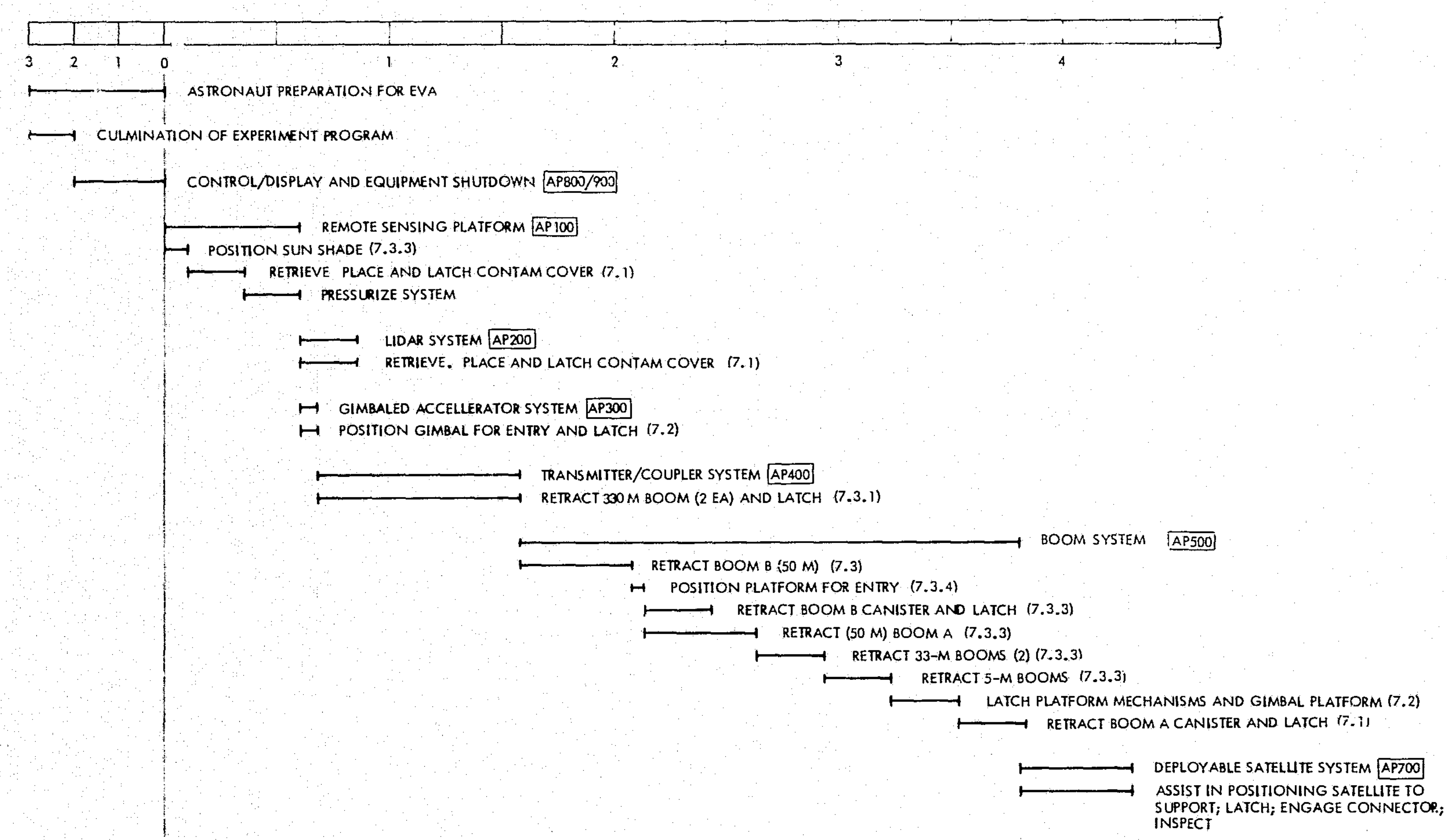


Figure 3-39. AMPS - Preparation for Return, EVA Mode

3.13 ADVANCED TECHNOLOGY LABORATORY (ATL)

The ATL is a dedicated 7-day sortie mission consisting of a multi-disciplinary payload mounted on a standard five-section Spacelab pallet. The multi-disciplinary payload contains portions of such disciplines as navigation, earth observations, physics, and chemistry, and environmental effects on material. Its orbital altitude is approximately 350 km (190 nm) at a 57-degree inclination.

The five-section pallet utilizes the entire interior of the Shuttle bay. Consequently, only controls and displays are located internally in the Shuttle cabin at the payload specialist station. The other electronics which does not require man interface but does require a pressurized environment are located in equipment igloos strategically positioned about the pallet.

The ATL payload selected for this study is defined in the SSPD study as "ATL P/L No. 5 (pallet only), ST-23S". It consists of 12 uniquely defined experiments, each having its own set of equipment items. The baseline payload configuration is illustrated in Figure 3-40.

Microwave Interferometer. Overall objective of this experiment is to obtain engineering test data in the low altitude space environment which allows a position location system to be designed for geosynchronous orbit. The experiment equipment consists of a vernier helicone antenna and pre-amplifier at each end of four extendable orthogonal booms whose extended length is 38 m each (125 feet). Cables running along the booms connect the preamplifiers with a radio receiver located at the hub of the boom mount. A second set of three coarse helicone antennas are located around the boom mount hub. The booms are retracted and stowed in canisters during launch and entry operations.

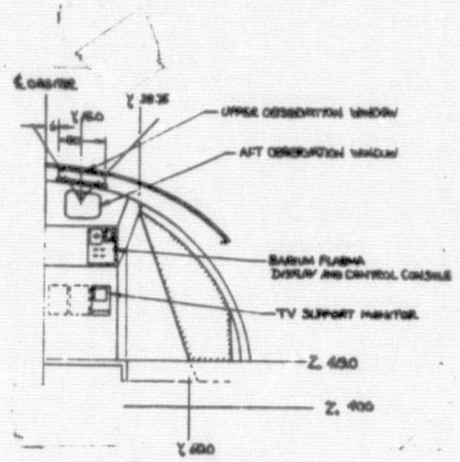
Smaller electronics and other associated support equipment are either boom mounted, pedestal attached or located in an equipment igloo. Other related electronics, controls and displays are in the PSS.

Microwave Radiometer. This experiment is designed to develop and test new microwave components and techniques, make day/night measurements of ocean temperature and sea state, and measure radio-frequency radiation from galactic sources.

The major equipment item of this experiment consists of a pallet-mounted deployable horn antenna and the antenna support structure. The horn structurally consists of an inflatable balloon of the appropriate configuration and RF surface characteristics. The horn opening is attached to a circular frame at one end and the throat is attached to the basic supporting antenna structure. Supporting electronics and associated hardware are located either attached to the basic support structure or in the equipment igloo. Man-interface equipment is located at the Shuttle PSS.

In the baseline mode a motor drive system unlatches the horn support ring from the basic support platform and telescopic tubes (4 each) are then driven outward extending the horn antenna. Upon full extension of the system the telescopic tubes are locked in place. The antenna horn is then pressurized to provide a smooth rigid inner surface.

ITEM	FUNCTION	SYSTEM
1	DEPLOY SEARCH, RESCUE & IMAGING RADAR EXPR.	ELECTRO MECHANICAL LATCH RELEASE & SERVO ACTUATED ELEVATION MECHANISM
2	EXTEND NEUTRAL GAS EXPERIMENT	SERVO ACTUATED LATCHES & EXTENSION MECHANISM
3	ACTIVATE BARIUM PLASMA CLOUD EXPR.	ACTUATE SERVO LATCHES & GIMBAL DRIVE & POINTING MECHANISM
4	EXTEND MICROWAVE RADIOMETER	ACTUATE SERVO LATCHES, DETENTS & POWER UNITS FOR EXPR. EXTENSION
5	DEPLOY NON-METALLIC EXPERIMENT	SERVO ACTUATED MECHANISM FOR BOOM EXTENSION
6	DEPLOY MICROWAVE INTERFEROMETER	ELECTRO MECHANICAL RELEASE LATCHES & SERVO ACTUATED DEPLOYMENT DRIVE SYSTEMS
7	ACTIVATE UV METEOR SPECTROSCOPY EXPR.	SERVO ACTUATED LATCHES, SPRING LOADED HINGE COVERS
8	ACTIVATE LIDAR MEASUREMENTS EXPR.	ELECTRO MECHANICAL LATCHES & SPRING LOADED HINGED CONTAMINATION COVER
9	RELEASE AUTONOMOUS NAVIGATION EXPR.	ACTUATE LATCHES & ACTIVATE GIMBALLED DRIVE & POINTING MECHANISM



SECTION AT APPROX. X-550
VIEW LOOKING AFT
PAYLOAD SPECIALIST STA.

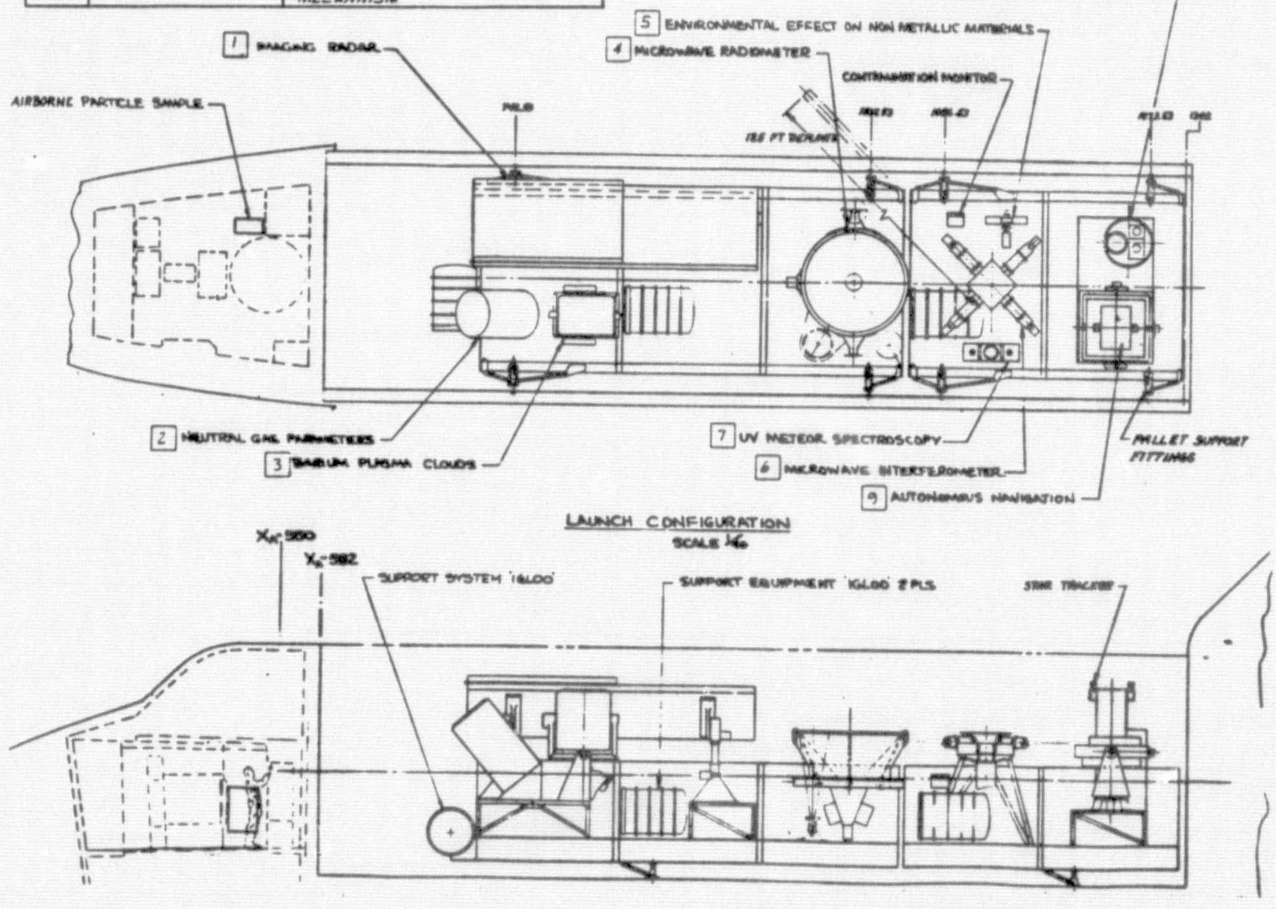


Figure 3-40. Baseline ATL Payload

Autonomous Navigation. This experiment is to determine the utility, limitations, and accuracy of a number of navigation techniques for determining orbital position relative to earth ground track; measure sensor accuracy and overall system error to aid in testing analytical error models; and flight test a holographic star field/landmark tracker and ground beacon tracker.

The experiment utilizes a single telescope which is time-shared for both star field and landmark tracking and is coupled to a coherent optical parallel image correlator with an inertial reference unit. The equipment is mounted within a platform assembly that presumes a Shuttle roll maneuver for target viewing. The holographic star field and landmark tracker uses a 20-cm clear aperture Schmidt-Cassegrain telescope with an 8-degree field of view, a laser, wafer image intensifier, paraboloidal mirror segments, fixed multiplexed matched spatial filter, image dissector electro-optical readout system, and an input imaging device.

The star field tracker, ground tracker, and TV camera are mounted within the envelope of a contamination container under a slight over pressure. The container pressure is remotely released and a drive mechanism uncovers the optical sensors within and the gimbal platform is unlocked.

Search and Rescue/Imaging Radar. The search and rescue aids experiment is used to determine the utility, limitations, and accuracy of detecting, identifying, and positioning earth-located passive targets on vehicles in emergency situations. It employs a side-looking radar system to develop, test, and demonstrate RF passive targets; determine and demonstrate the capacity of an orbiting radar system to maintain tracking data on classess of mobile platforms equipped with passive targets; and examine the relative system advantages of passive and active targets for use in search operations.

This experiment utilizes an imaging radar which employs a side-looking synthetic aperture technique. The experiment also uses the imaging radar to record radar return data on photographic film from which post-flight processing can provide accurate earth surface maps for use in analytical evaluations of basic radar technology.

Both activities utilize the same equipment. The primary equipment item is a long narrow single unit slotted waveguide antenna (1.98 x 0.15 x 9.14 m) mounted within the Shuttle bay. The antenna is mounted on two telescoping booms which allows the antenna to be raised outside the mold line of the Shuttle.

Lidar Measurements of Cirrus Clouds and Lower Stratospheric Aerosols. This experiment measures the spatial distribution of cirrus clouds and lower straospheric aerosols. The lidar system consists of a pulsed laser transmitter monostatically aligned with a reciving telescope. In addition, a photographic camera is boresighted with the nadir-pointed lidar.

All the experiment scientific equipment items are installed in a cylindrical contamination chamber. The contamination chamber has a slight over pressure that must be relieved; the contamination cover must also be removed and secured; and the gimbal system unlocked. All of these functions are performed remotely at the PSS within the orbiter.

Barium Plasma Cloud Release of Sunward Side of Earth. This experiment monitors the natural magnetospheric plasma convection patterns on the sunward side of the earth. Equipment for this experiment consists of a photometer, photographic camera with intensifier, an aiming TV camera, and an environmental control unit. Since the majority of the experiment equipment items are optical, they have been enclosed in a contamination chamber which is mounted on a gimbal system. In the baseline mode the contamination chamber must be depressurized, the rotating lens cover must be displaced, and the gimbal system must be unlocked.

Mapping of Upper Atmospheric Neutral Gas Parameters. This experiment measures the neutral number density of each constituent of the upper atmosphere and the temperature of the upper atmosphere as a function of latitude, longitude, height, and time using molecular beam techniques on a global scale.

This experiment consists of a set of molecular beam mass spectrometers mounted on a boom and deployed into the undisturbed free stream through which the spacecraft is traveling to measure the neutral number density and temperature. The mass spectrometer system consists of a free-stream ion source, a quadrupole mass filter, an ion-counting collector system, and associated electronics. Except for the electronics, the entire system must be vacuum-sealed during launch to protect the vacuum integrity of the instrument. After obtaining orbit, the instrument is opened and deployed into the free stream to avoid measuring surface-scattered gas.

The configuration requires two mechanized systems to deploy the sensor; one is used to uncover the instrument module and the other to deploy and retract the sensor boom.

Ultraviolet Meteor Spectroscopy from Near-Earth Orbit. The objective of this experiment is to obtain high-quality meteor spectrographs of the atmospheric zone. The major equipment items form a complex of spectrographs consisting of a Carruthers far-UV spectrograph, an electronographic spectrograph, and a middle UV panchromatic spectrograph plus a photomultiplier detector. These units are mounted within a slightly over-pressurized contamination chamber which is attached directly to the Spacelab pallet.

Environmental Effects on Non-Metallic Materials. The object of this experiment is to collect in situ data on the effects of the near-earth space environment of elastomers, coatings, and polymeric films. The experiment consists of samples in vacuum-tight containers. Both arrays are deployed by a single extendable boom. With the boom fully extended, the samples are unsealed and exposed to the space environment by mechanically removing covers from the array containers, positioned to obtain the maximum sunlight possible without active solar orientation. The experiment is completely passive. Prior to entry, the array containers are resealed, the boom retracted, and the samples maintained in vacuum storage until delivery to the ground for analysis. Since exposure to oxygen can eliminate the effects of radiation on many of these materials, the integrity of the vacuum seal on these canisters is essential.

Contamination Monitor. This experiment monitors contamination in the orbiter cargo bay. It consists of a series of passive sensors mounted in the orbiter bay monitoring contamination of different locations. Groups of sensors will be sequentially exposed to the environment. The sensors monitor contamination from initial installation through to Shuttle landing rollout.

3.13.1 Baseline Payload Operations Definition

Following orbit establishment and a sleep period, the Spacelab is activated and the ATL experiments equipment deployment begins. The ATL payload pallet-mounted equipment can be deployed sequentially and operated as required for the duration of the mission. The experiments in some cases can be operated without man-interface. Others requiring a man-interface will be attended on a single shift basis. Detailed operation of the experiments has yet to be determined. ATL experiments are completed at 152 hours (GET) after which the deployed sensors are stowed within the mold line of the Shuttle bay for entry. Total mission duration is 166 hours and 26 minutes.

The baseline mission operation is performed totally from the Shuttle payload specialist (PS) station. The time schedule and sequence of operations to prepare the 12 experiments for operation are presented later. Approximately 2.2 hours is required for deployment of the sensors from the PS station. The procedure used was to deploy those sensors which require greater caution through to those which are simply exposed (i.e., microwave interferometer to contamination monitor, respectively).

Payload Specialist Station. At some appropriate time during the early portion of the mission following the establishment of the final orbit, the crew will begin to perform a status, monitor, check, and configuration of the payload specialist station. Approximately 30 minutes will be required to proceed through a comprehensive checklist. Having satisfactorily completed the checkout, the crew may now proceed to begin deployment of the various sensors.

Microwave Interferometer. The major deployable units of this experiment are the four 38-m (125-ft) Astromast booms. The PS operator unlatches the boom boost latches and commands deployment of the four masts simultaneously. The booms travel at a 1.5-m (5 ft)/minute rate requiring 25 minutes for transit. With unlatching and deployment approximately 30 minutes is required for deployment which also includes confirmation that the booms have extended the prescribed distance.

Autonomous Navigation. While the microwave interferometer is in transit, the PS operator commands the autonomous navigation contamination container to be depressurized, the contamination cover to be removed, and the gimbal boost lock to be unlatched. This task is of short duration and is not expected to exceed 0.1 hour. Nor should it be of such complexity to distract the PS operator from the deployment of the interferometer booms.

Microwave Radiometer. This unit consists of an inflatable horn antenna with an upper antenna ring positioned by four telescopic booms. Its deployment, like that of the microwave interferometer, requires rather close attention by the PS operator to ensure smooth and even deployment. Once the boost latches release the upper horn ring support, the four telescopic-type booms begin to deploy it along with the deflated antenna horn. Upon completion of the extension process, the horn-bag is pressurized to form the appropriate configuration. This process should not exceed 0.5 hour.

Search and Rescue/Imaging Radar. The sidelooking radar antenna system is used to support two separate experiments as indicated. This unit is the third largest in size and in deployment complexity. The PS operator commands the antenna itself to unfold and lock in place. The boost latches on the support structure are undone remotely and the booms raised such as to position the SLR antenna beyond the mold line of the Shuttle. Once in place the extension devices are locked in place. This entire procedure is not anticipated to exceed 0.2 hour.

Mapping of Upper Atmospheric Neutral Gas Parameters. This group of molecular beam mass spectrometers is mounted in an evacuated contamination container along with a deployment boom. Following the deployment of the SLR antenna, the PS operator turns his undivided attention to the deployment of this unit. The container latches are undone and the hatch cover removed sufficiently to allow the lengthy deployment boom to be extended. The boom, which is 22.8 m (75 ft) in length, is deploy forward and above the Shuttle cabin in the free stream at 0.0316 m per second. The necessity for slow extension is to minimize induced oscillation into the boom during deployment.

Ultraviolet Meteor Spectroscopy from Near Earth Orbit. This unit operates in the optical wavelength region and any particulates or film deposits tend to seriously degrade the narrow operational wavelength bands. Consequently this unit is sealed in a slightly over-pressurized contamination container during liftoff and entry. During the preparation for operation phase the PS operator verifies that the container is totally depressurized. The container cover latches are undone and the cover is locked in the stowed position. Once activated, the unit remains in standby until it senses the unique phenomena which then activates the recording system. Approximately 0.1 hour is adequate to prepare the sensor for operation.

Lidar Measurements of Cirrus Clouds and Lower Stratospheric Aerosols. The lidar unit and telescope are mounted in a contamination container during launch and entry under a slight over-pressure which bleeds down as the Shuttle attains its prescribed orbit. At the appropriate time in the early mission phase, the PS operator verifies that the pressure has bled down to the ambient conditions of space. He unlatches the cover locks, removes the cover stowing it and proceeds to unlatch the boost locks. Approximately 0.2 hour has been allotted to these tasks which are all performed remotely from the PS station.

Contamination Monitor. As described earlier, the randomly located sensor heads and central analysis system are activated very early in the Shuttle preparation phase (experiment installation in the Shuttle while still in the horizontal position). The unit remains on through landing till the equipment has been removed from the Shuttle bay (post landing). The scheduled 0.1 hour is included for periodic checks.

Environmental Effects On Non-Metallic Materials. This unit, containing an assortment of nonmetals, is prepared and maintained in an evacuated condition from the time of manufacture to time of analysis. The PS operator unlatches the vacuum sealed container cover latches, removes the cover, and deploys the unit out of the bay such that it can retain a position of maximum sun absorption.

Barium Plasma Cloud Release on Sunward Side of Earth. This experiment consists of optical instruments which are deployed later in the mission. Much coordination is required with the ground launching crew to ensure that the barium-bearing rocket will be launched at the appropriate time. Since the optics are subject to contamination, it is not planned to deploy the sensors until the experimenters are in complete accord. Therefore the time bar has been omitted from the schedule but should not exceed 0.1 hour for preparation.

3.13.2 EVA Applications

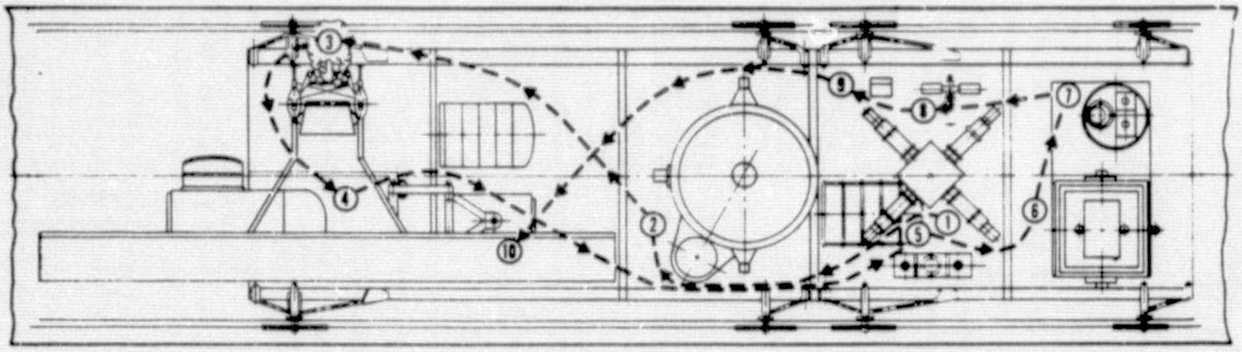
The major areas of EVA applications are in the pre-operations phase where a substantial amount of EVA is used to deploy the various sensors. Once the operational orbit has been established and the crew rested, the pre-operation phase may begin. While the Shuttle crew is preparing the Shuttle for experiment operations, the EVA crew can be pre-breathing for acclimation to perform EVA (3.7 psi suit) activity.

The EVA activity required to support pre-operations functions requires, at a minimum two astronauts in space suits and at least one in the Shuttle cabin at the PS station. Although no specific requirement was found for the RMS, it may be of some value to have the RMS manned. In addition, it was felt that several CCTV cameras will be required to support the EVA astronauts. The complexity of this payload becomes obvious when one examines the crew translation route depicted in Figure 3-41. The route shown is based on the deployment complexity of the payload. Each of the circled numbers represents a sequenced work station for that equipment item. Item 1, the microwave interferometer is probably the most sensitive in that it has four Astromasts which must be deployed 38.1 m (125 feet) each. The initial deployment phase requires rather close attention to ensure satisfactory deployment. The subsequently sequenced items are classified (and deployed) in order of complexity and safety of deployment.

Although the route appears circuitous and overlapping, it does not appear that an excessive amount of EVA work aids will be required for translating about the pallet area. Sufficient open areas and push-off points are available to assist the astronauts movements.

Microwave Interferometer (1). The microwave interferometer cruciform deployable-boom system is mounted on the aft third portion of the pallet. This location requires both astronauts upon egressing from the airlock to travel back to the interferometer. The two astronauts position themselves such as to observe the deployment process and to assist as required. A hand-held power unit is attached to the boom drive system by one astronaut while the other unlatches the boom tips from the individual boom canisters. Two opposing booms are deployed simultaneously. This allows each astronaut to observe one boom arm as it deploys. Upon deployment, the remaining opposed booms are deployed. The sequence requires 25 minutes each for a total of 50 minutes.

Microwave Radiometer (2). This unit is mounted forward of the microwave interferometer between two of the booms and midway on the pallet. The astronauts position themselves opposite each other and unlatch the boost latches on the antenna upper ring. Each astronaut then removes a support boom section and both begin to raise the upper support ring with the support booms. The boom sections are approximately 1.52 m (5 ft) sections; therefore, as each section is



STATIONS	INSTRUMENTS
1	MICROWAVE INTERFEROMETER
2	MICROWAVE RADIOMETER
3	SEARCH, RESCUE, AND IMAGING RADAR
4	NEUTRAL GAS PARAMETER EXPERIMENT
5	UV METEOR SPECTROSCOPY
6	AUTONOMOUS NAVIGATION
7	LIDAR MEASUREMENTS OF CIRRUS CLOUDS
8	NONMETALLIC MATERIALS EXPERIMENT
9	CONTAMINATION MONITOR
10	BARIUM PLASMA CLOUD EXPERIMENT

Figure 3-41. ATL Payload EVA Operations

raised its length, another section is added and the support ring raised till the antenna is extended to its operational height.

The astronauts then move 90 degrees to their initial posision and begin to assemble all the pole sections for that side and insert them into the proper inserts. The antenna horn which is made of an inflatable material, is hoisted with the support ring. Once secured, one of the astronauts begins to pressurize the inflatable portion of the horn until it is rigid. Figure 3-42 depicts the above procedure.

Search and Rescue and Imaging Radar (3). From work station 2, one astronaut moves to the large side looking radar antenna and positions himself at that work station. The other astronaut moves to the various antenna boost locks and proceeds to unlatch each one. Once unlatched the long slender antenna is manually rotated outward into its operational position and the antenna itself is properly angled if required by the astronaut (see Figure 3-43).

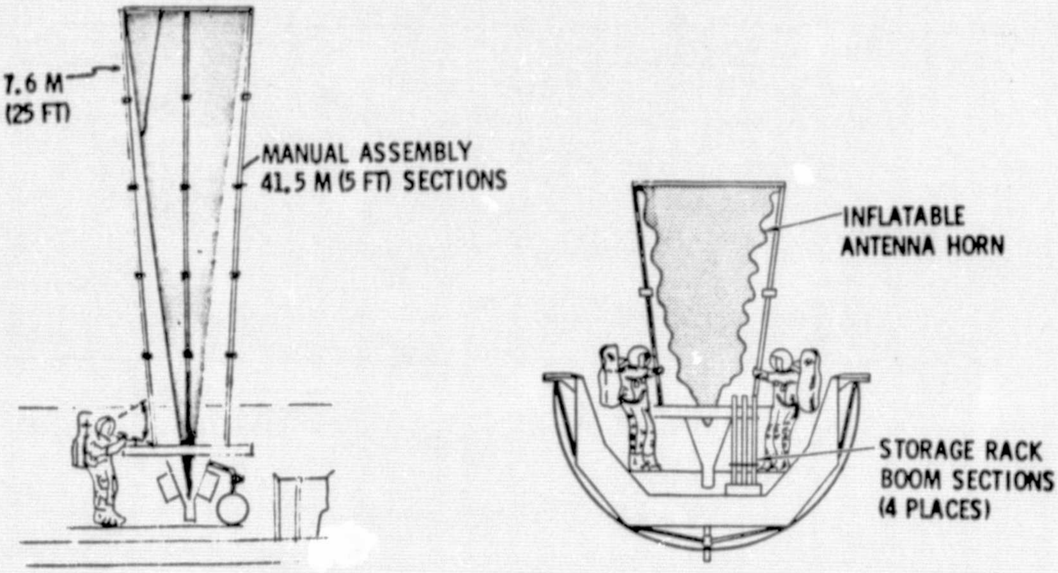


Figure 3-42. EVA Deployment of Radiometer Antenna

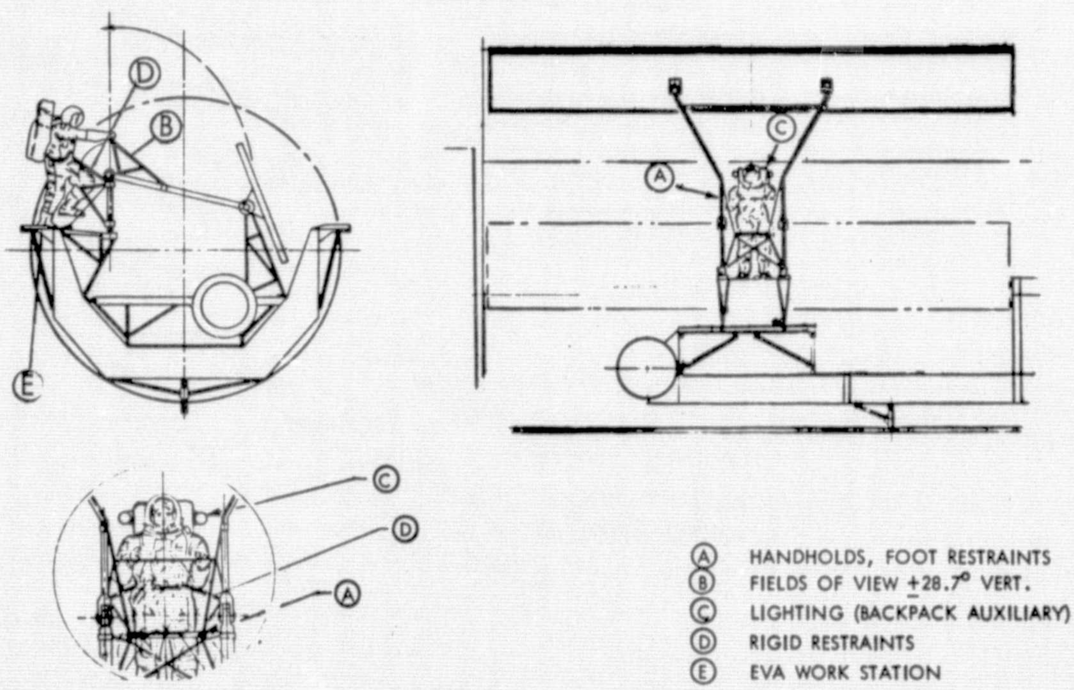


Figure 3-43. Deployment of SLR Antenna

Mapping of Upper Neutral Gas Parameter Experiment (4). The neutral gas measuring device is stored in an evacuated container prior to launch to maintain maximum cleanliness. One of the astronauts positions himself at this work station and removes and stows the contamination cover. He then unlatches all boost latches on the device within the container.

After completion of the unlatching task, the sensor device, which is mounted on the end of a 22.9-m (75 ft) boom, is driven outward using an astronaut handheld power drive unit. Once the unit is deployed, the boom system is locked in place.

Ultraviolet Meteor Spectroscopy (5). One astronaut moves to the UV spectroscopy equipment located between the two port booms of the microwave interferometer. He vents the contamination container, removes and stows the cover, and inspects the unit for obvious damage or contamination on the camera and UV spectroscope lenses. In addition, he will load film as required.

Autonomous Navigation (6). This equipment is mounted on the aft portion of the pallet. Since the unit is rather large, one astronaut vents any residual pressure in the contamination chamber and the other positions himself to unlatch the contamination cover, remove it, and hand it to the other to stow. The equipment in the chamber is then inspected visually. The astronaut on the unit then dismounts and both astronauts remove the gimbal system boost latches.

Lidar Measurements of Cirrus Clouds (7). One astronaut proceeds to the lidar unit which is located at the rear-most position on the pallet adjacent to the autonomous navigation unit. He positions himself in the foot restraints and begins by venting the contamination container. The cover latches are unlatched and the cover is removed and stowed. After performing a visual inspection of the unit, he then removes the boost locks on the gimbal system.

Environmental Effects on Non-Metallic Materials Experiment (8). One astronaut moves to the non-metallic materials unit mounted between the two starboard deployable booms of the microwave interferometer. He removes the contamination cover exposing the specimen and unlatches the boost latches. Using the handheld power drive tool, he extends the specimen tray the prescribed height.

External Contamination Measurements (9). It is noted that this unit is continually monitoring the Shuttle bay area from early in the ground checkout phase, throughout the mission, and down to removal of the payload. The only astronaut inflight interface is to visually check the main unit and satellite monitors throughout the bay area.

Barium Plasma Cloud Release on Sunward Side of Earth (10). The last experiment equipment to be activated is the barium cloud unit which is mounted on the port side behind the neutral gas unit. Due to its size, the unit is rotated on its side with the longitudinal axis parallel with that of the pallet. The astronaut unlatches the boost locks and erects the unit perpendicularly to the pallet locking the erection latches. The contamination cover is verified as depressurized and the cover latches are unlatched. The cover is then removed and stowed. The system is visually inspected and film is loaded into the cameras as required.

3.13.3 Operations Analysis

Operations Cycle

The first-level operations cycle block diagram for the ATL is shown in Figure 3-2. The figure shows a single continuous flow which is applicable for either baseline or EVA operations.

Sequence Comparisons

Several of the experiments discussed below can substantially be modified for application of EVA. For example, the microwave radiometer can utilize EVA to erect the inflatable horn antenna by deleting the complexity of mechanization and manually extending the horn antenna using light-weight pole sections. The search and rescue side looking radar antenna also may be deployed simply by removal of automated extension devices and replacing the erection cycle by using an EVA astronaut to rotate the SLR antenna to its operational position. Table 3-14 presents the ATL sequences.

In addition, nearly all the smaller sensors and experiment equipment are mounted in a contamination container and/or on an instrument pointing system. In nearly all cases, the astronaut can replace the complex electromechanical devices (cover locks, cover removal drive devices, remote pressurization systems, Astromast deployable booms, etc.), do a better job of visually inspecting the units, and if required, replace or add consumables (i.e., film, cryogenics, exotic gases, etc.). For complete details, a comparison of the identified sequences of activities should be compared with the detailed drawings.

No specific sequencesof operations are defined for several of the EVA applications areas. The following list identifies these areas along with the reason for omission.

Operations Area	Sequence Omission
2.0 Experiment Operations	EVA is not planned nor is required for normal operations.
3.0 Contingency Operations	Dependent on type of contingency. Each must be handled on a real time basis.
4.0 Separate Spacecraft	Not applicable to sortie missions.
5.0 Docking Operations	Not applicable to sortie missions.
6.0 Planned Maintenance	Experiment and equipment dependent. Photographic film replacement similar to pre-operations.
7.0 Prepare for Return	Inverse process of pre-operations. The exception is for non-recoverable items, the launching mechanisms are secured for entry.

Table 3-14.
ADVANCED TECHNOLOGY LABORATORY
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	**Payload Functional Reqmts.**	**Sequence**	**Payload Functional Reqmts.**
1. PRE-OPERATIONS			
MICROWAVE INTERFEROMETER			
		Proceed to interferometer work area	Handholds, foot restraints, work platform
1.2 DISENGAGE BOOST/LOCKS (Interferometer boom)			
Basic sequences			
1.3.3 EXTEND INSTRUMENT BOOMS			
Partially deploy booms to pre-operational checkout position	PSS control console, boom deployment system	See baseline	See baseline
		Observe/assist boom deployment	EVA astronaut
		Manually latch boom in operational position	Boom latches
1.8 TEST AND CHECKOUT			
Basic sequences			
MICROWAVE RADIOMETER			
1.2 DISENGAGE BOOST LATCHES (Antenna structure)			
Unlatch radiometer boost latches on antenna structure	PSS control console, antenna boost latches	Unlatch boost latches on antenna support ring	
1.3.3 EXTEND INSTRUMENT BOOMS			
Deploy flexible horn antenna structure	PSS control console, horn structure	Attach first of 4 support ring poles at 2 opposing positions	Support ring poles
	Motor-drive bi-stems	Continue till support ring is positioned	Support ring poles
Lock extension mechanism	PSS control console	Attach and implace the opposing pole sections	Support ring poles
		Deploy antenna/ring by pulling lanyard to full extension and secure lanyard	Horn antenna deployment system
		Pressurize flexible antenna structure	Antenna pressurization system
		Inspect deployed antenna sys.	Visual inspection
1.8 TEST AND CHECKOUT			
Basic sequences			
AUTONOMOUS NAVIGATION			
1.1 REMOVE CONTAMINATION SHIELD			
Depressurize contamination container	PSS control console, vent valve	Depressurize contamination container manually	Vent valve
Basic sequences			

Table 3-14. (continued)

ADVANCED TECHNOLOGY LABORATORY

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
1.2 DISENGAGE BOOST LATCHES (Gimbal system)			
Unlatch gimbal system boost latches	PSS control console, gimbal system and latches		
1.8 TEST AND CHECKOUT			
Basic sequences			
SEARCH AND RESCUE AND IMAGING RADAR			
1.2 DISENGAGE BOOST LATCHES (SLR)			
Basic sequences			
1.3.4 EXTEND MECHANISM			
Basic sequences			
Orient SLR antenna to proper angle	PSS control console	Manually rotate antenna outward to operational configuration; lock rotation mechanism	Antenna rotation device
1.8 TEST AND CHECKOUT			
Basic sequences			
LIDAR MEASUREMENTS OF CIRRUS CLOUDS			
1.1 REMOVE CONTAMINATION SHIELD			
Depressurize lidar contamination container	PSS control console	Depressurize lidar contamination container	Container vent system
Basic sequences			
1.2 DISENGAGE BOOST LOCKS (LIDAR gimbal system)			
Basic sequences			
1.8 TEST AND CHECKOUT			
Basic sequences			
Perform operational readiness checks	PSS control console	Perform operational readiness checks	PSS control console
BARIUM PLASMA CLOUD RELEASE ON SUNWARD SIDE OF THE EARTH			
1.2 DISENGAGE BOOST LOCKS			
Unlatch gimbal boost locks and erect sensor	Unit boost latches, pivoting device	Unlatch boost latches and erect sensor unit	Manual latch mechanism rotation device and lock
Depressurize sensor contamination container	PSS control console, pressure venting system	Depressurize sensor container	Manual vent valve
Unlatch, remove and stow container cover	Container latches, removal mechanism, cover securing device	Remove and stow container cover	Manual latches, cover, stowage device
Unlatch gimbal boost locking devices	PSS control console, gimbal boost locks	Unlock gimbal system boost locking device	Gimbal system locks

Table 3-14. (continued)
ADVANCED TECHNOLOGY LABORATORY
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
1.10 VISUAL INSPECTION			
Basic sequences			
1.5 LOAD FILM			
Baseline configuration requires full film loaded canisters		Load photographic film	Film cassettes
1.8 TEST AND CHECKOUT			
Basic sequences			
MAPPING OF UPPER ATMOSPHERIC NEUTRAL GAS PARAMETERS			
1.1 REMOVE CONTAMINATION SHIELDS			
Basic sequences			
1.2 DISENGAGE BOOST LOCKS (Sensor/boom latches)			
Basic sequences			
1.3.4 DEPLOY MECHANISMS			
Basic sequences			
1.8 TEST AND CHECKOUT			
Basic sequences			
1.10 VISUAL INSPECTION (Before deployment)			
Basic sequences			
ULTRAVIOLET METEOR SPECTROSCOPY FROM NEAR EARTH ORBIT			
1.1 REMOVE CONTAMINATION SHIELDS			
Depressurize contamination container	PSS control console, pressure venting system	Depressurize contamination container	Pressure vent system
Basic sequences			
1.5 LOAD FILM			
Baseline configuration requires full film loaded canisters		Load photographic film into camera(s)	Photographic film cassettes
1.8 TEST AND CHECKOUT			
Basic sequences			
1.10 VISUAL INSPECTION			
Basic sequences			

Table 3-14. (continued)

ADVANCED TECHNOLOGY LABORATORY

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
ENVIRONMENTAL EFFECTS ON NON-METALLIC MATERIALS			
1.1 REMOVE CONTAMINATION SHIELDS			
Basic sequences			
1.3.4 EXTEND MECHANISM (Container/boom)			
Basic sequences			
1.8 TEST AND CHECKOUT (Sensor tray check and pointing)			
Basic sequences			
EXTERNAL CONTAMINATION MEASUREMENTS			
(A) AMBIENT AIR MONITOR (AAM)			
Note: This unit is on continually monitoring ambient air during payload installation and checkout, launch preparation, ascent, descent, landing, and payload unloading.			
(B) ORBITAL ENVIRONMENT MONITOR (OEM)			
1.1 REMOVE CONTAMINATION SHIELD			
Unlatch and remove covers on remotely located units (5 TQCM's)	PSS control console	Unlatch, remove and stow contamination covers	Covers, latches and stowage mechanisms
1.8 TEST AND CHECKOUT			
Basic sequences			
7. PREPARE FOR RETURN			
Inverse of 1. PRE-OPERATIONS			

Timeline Comparisons

Figures 3-44, 3-45, and 3-46 reflect ATL Baseline - Preparation for Operations; EVA - Preparation for Operations; and EVA - Preparation for Entry, respectively. A typical mission operations timeline, Figure 3-47, was also prepared for the first 8 hours of mission operations indicating approximation of lighting conditions and subsequent mission EVA tasks.

Comparing the baseline with the EVA - Preparation for Operations (2.2 and 3.6 hours respectively), some 1.4 hours additional are required for the EVA mode. This is due to the additional time required for the astronaut to move about the larger equipment items performing manual operations. This time is consumed preparing primarily the microwave interferometer, microwave radiometer, the UV spectrometer, the lidar unit, and the neutral gas equipment.

It was assumed that the Preparation for Return in the baseline mode would be the inverse of the preparation for operations; therefore, only an EVA preparation for return is included. Approximately 0.2 hour more is required over the baseline.

A typical 8-hour mission operations period was analyzed based on the reference source data. Interspersed in Figure 3-47 are scheduled experiment activities along with a credible period of EVA that might be used to manually adjust experiment equipment and to activate the barium plasma experiment equipment.

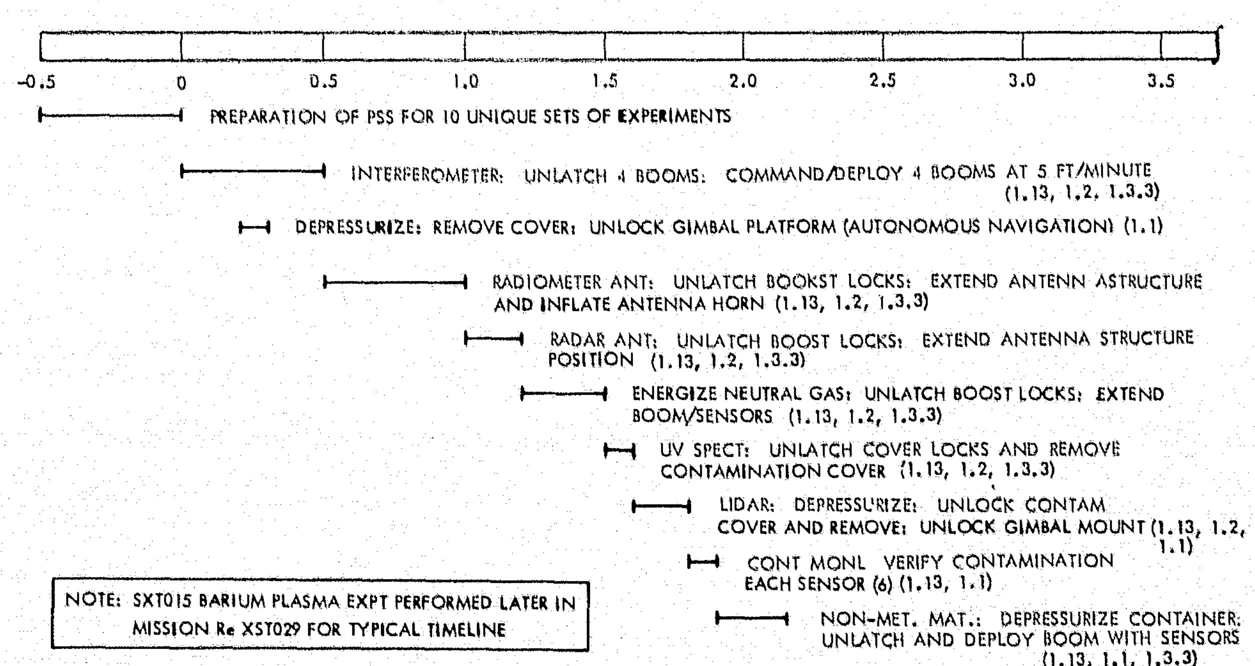
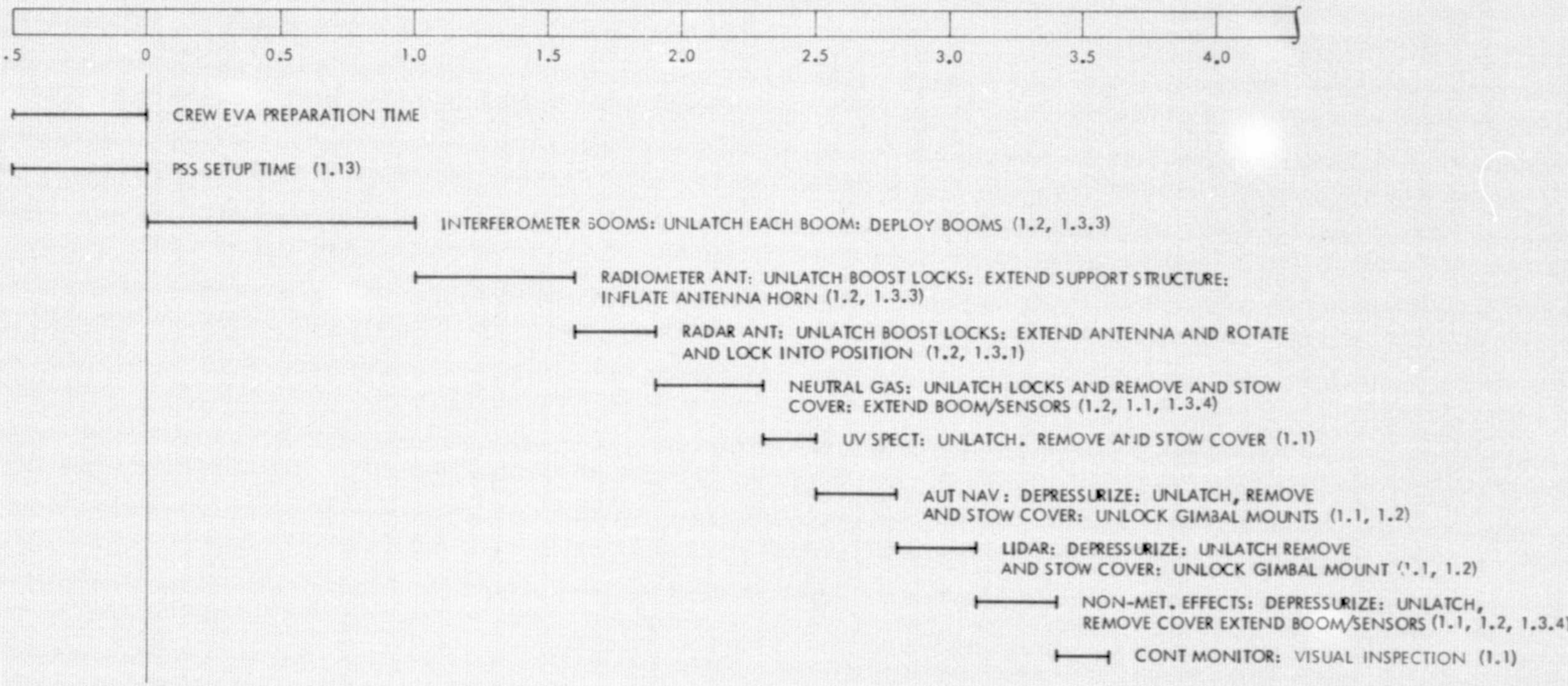


Figure 3-44. ATL - Preparation for Operation, Baseline Mode



NOTE: XST015 BARIUM PLASMA EXP AND PERFORMED LATER IN MISSION (TIMELINE REFERENCE XST029)

Figure 3-45. ATL - Preparation for Operation, EVA Mode

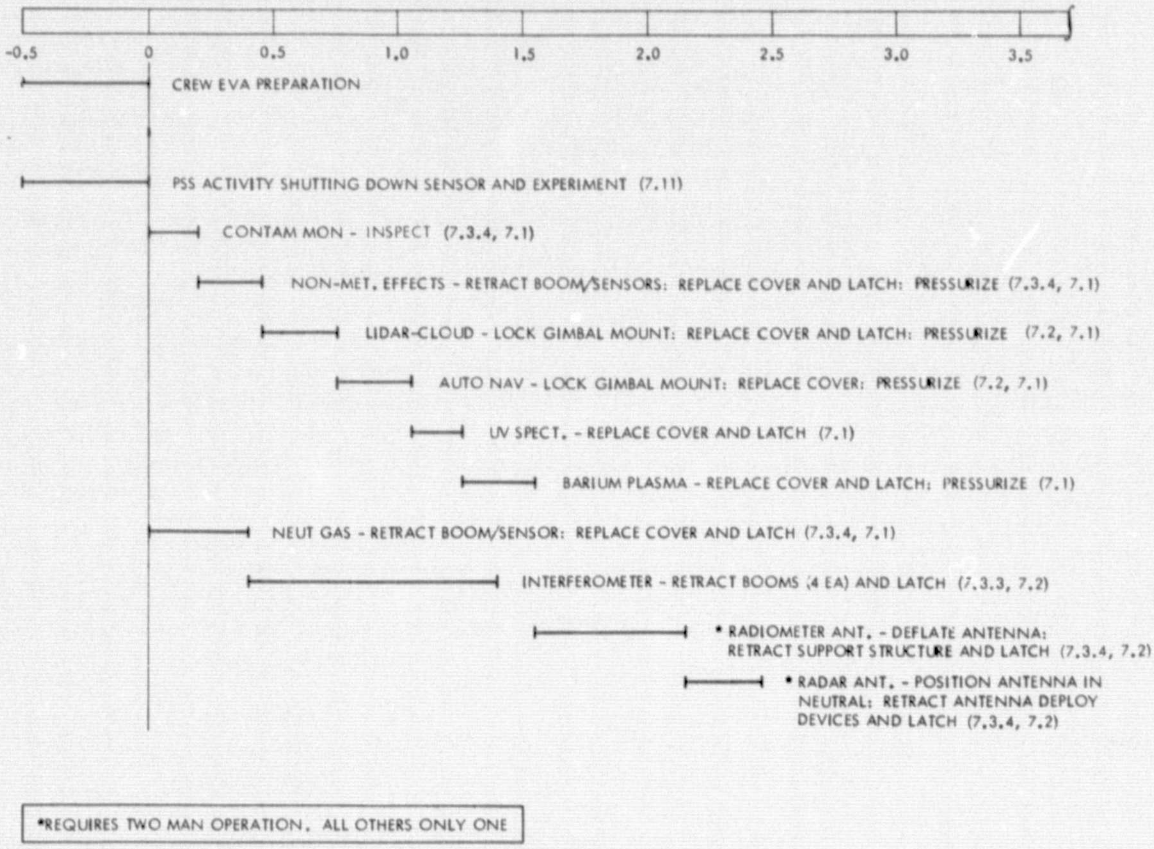


Figure 3-46. ATL - Preparation for Return, EVA Mode

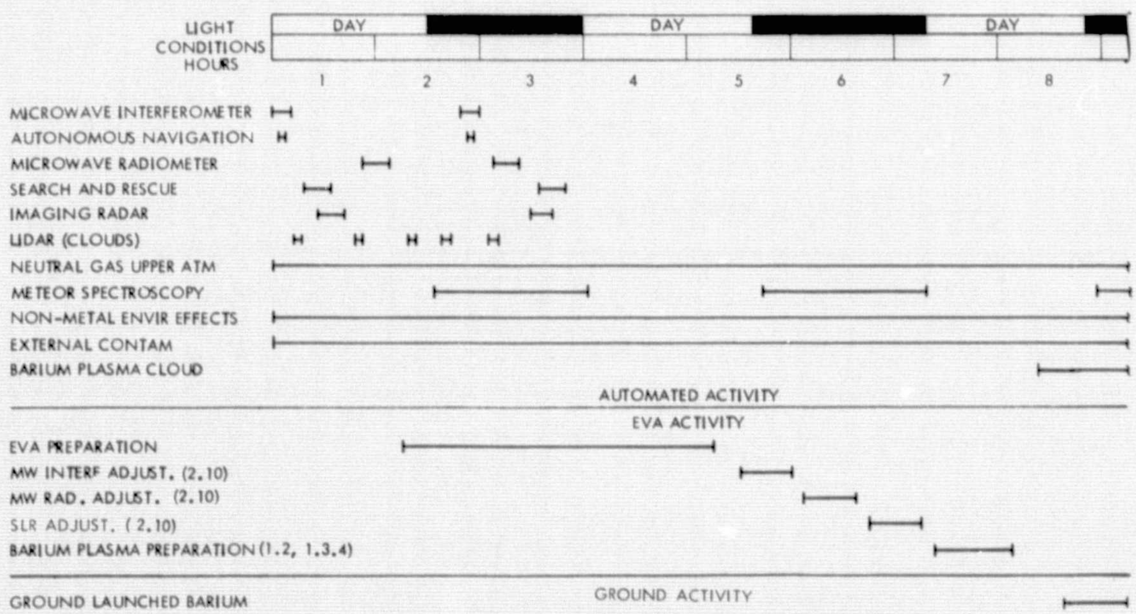


Figure 3-47. ATL - On-Orbit Experiment Operation
Typical Orbit Operations with EVA Activity

3.14 PHYSICS AND CHEMISTRY FACILITY

The facility consists of four unique investigation areas: (1) gas chemistry experiments in space, (2) mass and energy analysis of neutral species, (3) flame chemistry, and (4) ion beam experiments.

Approximately 650 kg of scientific and supporting equipment is required to perform these experiments. In addition, a pressurized Spacelab module is necessary. Each of the experiments to be performed requires either a complete vacuum or no influence of gravity or container system. More specifically, gas chemistry in space will study long-lived metastable species ordinarily lost to vessel walls. In the mass and energy of neutral species a better understanding of neutral species in which Shuttle gas chemistry experiments are performed will be attempted. Flame chemistry includes a comprehensive study of reactions due to the local environment. Ion beam experiments is a study of low-yield electron-ion neutralization processes.

Throughout this study, the experiment program was retained basically intact; however, a significant change was initiated to the Physics and Chemistry Facility baseline configuration to establish a more realistic EVA implementation.

Gas Chemistry in Space. The equipment in support of this experiment are physically divided into two groups, each mounted on separate platforms in separate airlocks of the Spacelab. One of the platform groups (A) is again subdivided into systems; (1) gas/atomizer system and (2) sensor system. The second platform (B) consists solely of sensors, both optical scanning and probe type.

Both platforms are raised above the Shuttle mold line into the free stream. Platform (A) is positioned forward of platform (B) with respect to flight direction. During the experiment period, selectable gases are atomized from the gas system into the free stream. The sensor system mounted on the same platform is positioned such as to scan through the gas vapor. Simultaneously, the sensor group on platform (B) also scans through the gas vapor but at a 90-degree position to the sensor viewing plane on platform (A). In addition, other non-scanning probe type sensors (electron probes, etc.) monitor the effects of the gas vapor as they pass through it. As the experiment progresses, other gases are interchanged.

Mass and Energy Analysis of Neutral Species. The major equipment item consists of an integral mass and energy analyzer mounted in a cylindrical structure which is deployed some 23 meters (75 feet) above the orbiter in the absolute free stream unperturbated by the orbiter. The unit is allowed to articulate such that its longitudinal axis is continually parallel to that of the flight path during operation.

The experiment once activated is relatively self-operating. Data are displayed in real time to the astronauts in the Spacelab allowing for monitoring and remote adjustment of the equipment.

Flame Chemistry. The flame chemistry experiment consists primarily of a combustion chamber with gas analysis, temperature monitoring, and photographic equipment mounted about its external periphery. In addition, accommodations are included to allow mounting of interchangeable gas cylinders for various types of gases (both oxidizer and fuel).

Various fuels/oxidizer combinations and mixture ratios are injected into the combustion chamber and ignited. The sensors monitor and record the various flame chemistry produced. The astronaut can monitor and evaluate the displayed data and change the various gases from the C&D panel. To replace sensors and film, and clean the combustion chamber, the combustion chamber must be retracted into the Spacelab through the science airlock.

Ion Beam Experiments. The ion beam equipment is configured somewhat similarly to that of mass and energy analysis of neutral species. It is a cylindrical structure deployed 23 meters (75 feet) above the orbiter in the unperturbed free stream. All the sensors are mounted within the cylindrical structure including gas storage bottles.

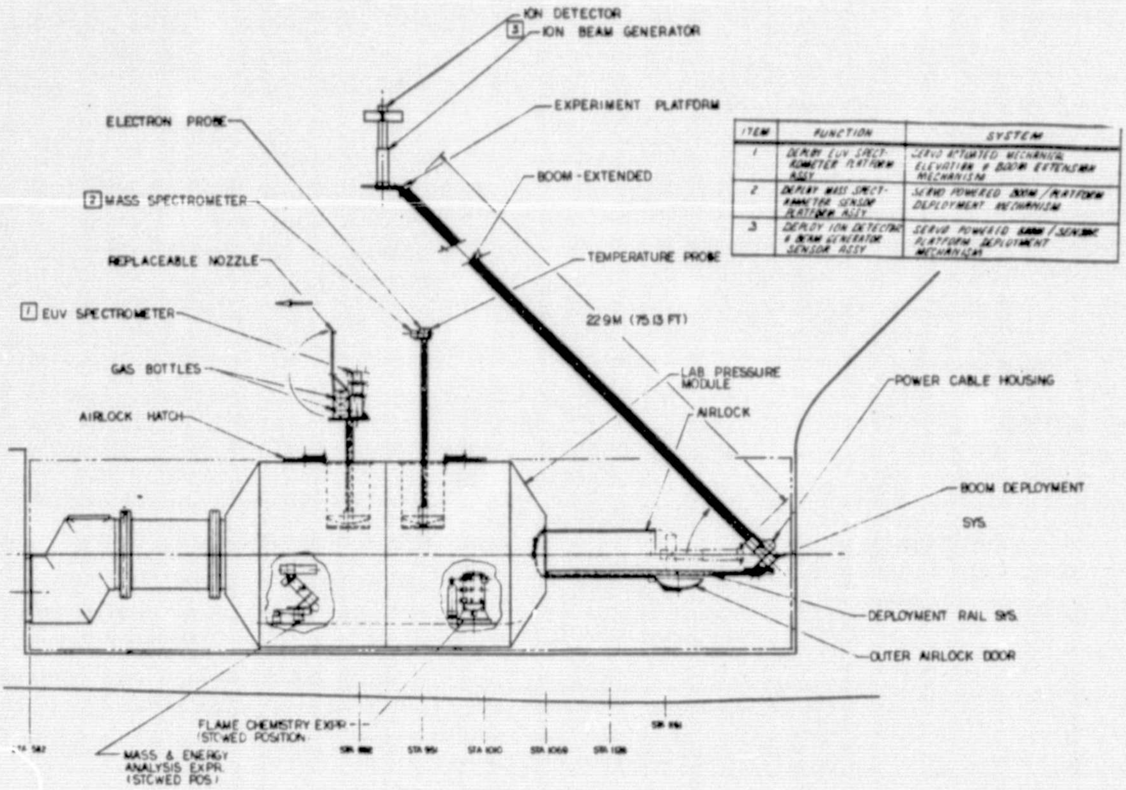
Once the equipment is deployed and activated it operates automatically relaying real-time information to the Spacelab support equipment. Real-time adjustments are permitted along with servicing of equipment as required.

It is noted that both the ion beam and the mass and energy analysis experiments are sensitive to Shuttle and other experiment-generated contamination. Care must be used to locate the sensors beyond such contamination or not to operate them during such periods.

The physics and chemistry facility payload baseline design consists of a long Spacelab module with two Spacelab-provided airlocks and a separate dedicated experiment airlock located in the aft end of the module (Figure 3-48).

All the experiments are performed in the space environment deployed through airlocks. During launch, entry and when not in operation, the equipment is stowed within the Spacelab with the exception of the ion beam, which is mounted in its dedicated airlock. The primary purpose of the airlocks is to allow the experiment equipment to be brought back into the Spacelab for change-out to other experiments and to permit maintenance of the equipment in a shirt-sleeve environment. It is noted that the standard 2-section Spacelab contains only two 1-meter (diameter) airlocks. Therefore, it will be necessary to remove and stow that equipment from the airlock which is not being used and inserting the desired equipment.

It is also noted that to obtain true results, not all the equipment items are compatible for simultaneous operation. Specifically, the mass and energy analysis of neutral species may be operated in conjunction with the ion beam experiment; however, the flame chemistry and the gas chemistry in space are not compatible, the reason being that the two latter investigations generate a substantial amount of contaminants during their normal operation.



ITEM	FUNCTION	SYSTEM
1	DEPLOY EUV SPECTROMETER PLATFORM ASSY	SERVO ACTUATED MECHANICAL ELEVATION & BOOM EXTENSION MECHANISM
2	DEPLOY MASS SPECTROMETER SENSOR PLATFORM ASSY	SERVO POWERED BOOM/PLATFORM DEPLOYMENT MECHANISM
3	DEPLOY ION DETECTOR & BEAM GENERATOR SENSOR ASSY	SERVO POWERED BOOM/SENSOR PLATFORM DEPLOYMENT MECHANISM

Figure 3-48. PCF Baseline Payload

3.14.1 Baseline Payload Operations Definition

The mission operation of the PCF as yet has not been solidified, consequently the following scenario for the baseline configuration appears to be a reasonable modus operandi.

Ion Beam Experiment. The ion beam sensor is stowed in a dedicated airlock attached to the aft end of the Spacelab during both launch and entry. In order to deploy the unit, the sensor dedicated airlock is depressurized remotely. Depressurization completed, the airlock external hatch is remotely opened and the sensor and sensor boom are deployed. When totally deployed from the airlock, the boom base is latched in place and the sensor erected to its operational position. The sensor system, mounted on an Astromast unit is then deployed outward to a position above and forward of the Shuttle cabin approximately 23 meters (75 ft) from its base well within the undisturbed free stream about the orbiter. Following equipment checkout it is placed into the automatic mode and allowed to operate per programmed procedure.

The monitoring astronauts observe the real time data readout and remotely adjust the unit as required. At the conclusion of the experiment the ion beam sensor is retracted in the reverse order of deployment, back into its airlock.

For maintenance, the ion beam sensor is retracted into the airlock, thus giving the astronaut an opportunity to modify the sensor and replenish any expended gases without EVA.

Mass and Energy Analysis of Neutral Species. This experiment along with the ion beam experiment can be operated simultaneously with potential synergistic effects. The mass/energy sensor unit is stowed in the Spacelab during launch and entry. For operation it is mounted on a double Astromast boom (sensor boom and airlock boom) within one of the Spacelab airlocks. When installed, the airlock is depressurized and the hatch opened. The airlock Astromast deploys the sensor unit beyond the orbiter mold line. The sensor Astromast then places the sensor unit approximately 23 meters (75 ft) above and forward of the orbiter cabin.

Since the unit does not require any supporting fluids or gases, it does not contaminate the local surroundings and if placed forward of the ion beam sensor path of flight, both units can operate simultaneously. The purpose for the airlock mounting is to allow on-orbit adjustment and modification of the experiment equipment. At the completion of the experiment, the sensor unit is retracted into the airlock. The sensor unit and sensor boom are removed and stowed in the Spacelab for entry. The airlock Astromast boom remains in the airlock for use with other experiment equipment (i.e., gas chemistry in space).

Gas Chemistry Experiment in Space. During the prescribed time of the mission, the gas chemistry equipment, which is stowed in the Spacelab during launch and entry, is prepared for operation.

This experiment requires the simultaneous utilization of both Spacelab airlocks. One platform with sensor and atomizer equipment is mounted on the Astromast boom in the foremost airlock of the Spacelab and the other platform of sensors only is mounted on an Astromast boom in the aft Spacelab airlock.

The two airlocks are depressurized, opened, and the two equipment booms are extended beyond the mold line of the orbiter. The experiment is remotely controlled from the Spacelab. The airlock system allows the deployed items to be brought back to the shirtsleeve environment of the Spacelab for resupply of gas, changing of film and cleaning and exchange of sensors and special equipment. Tear down and stowage of the equipment is the reverse of the preparation for operation.

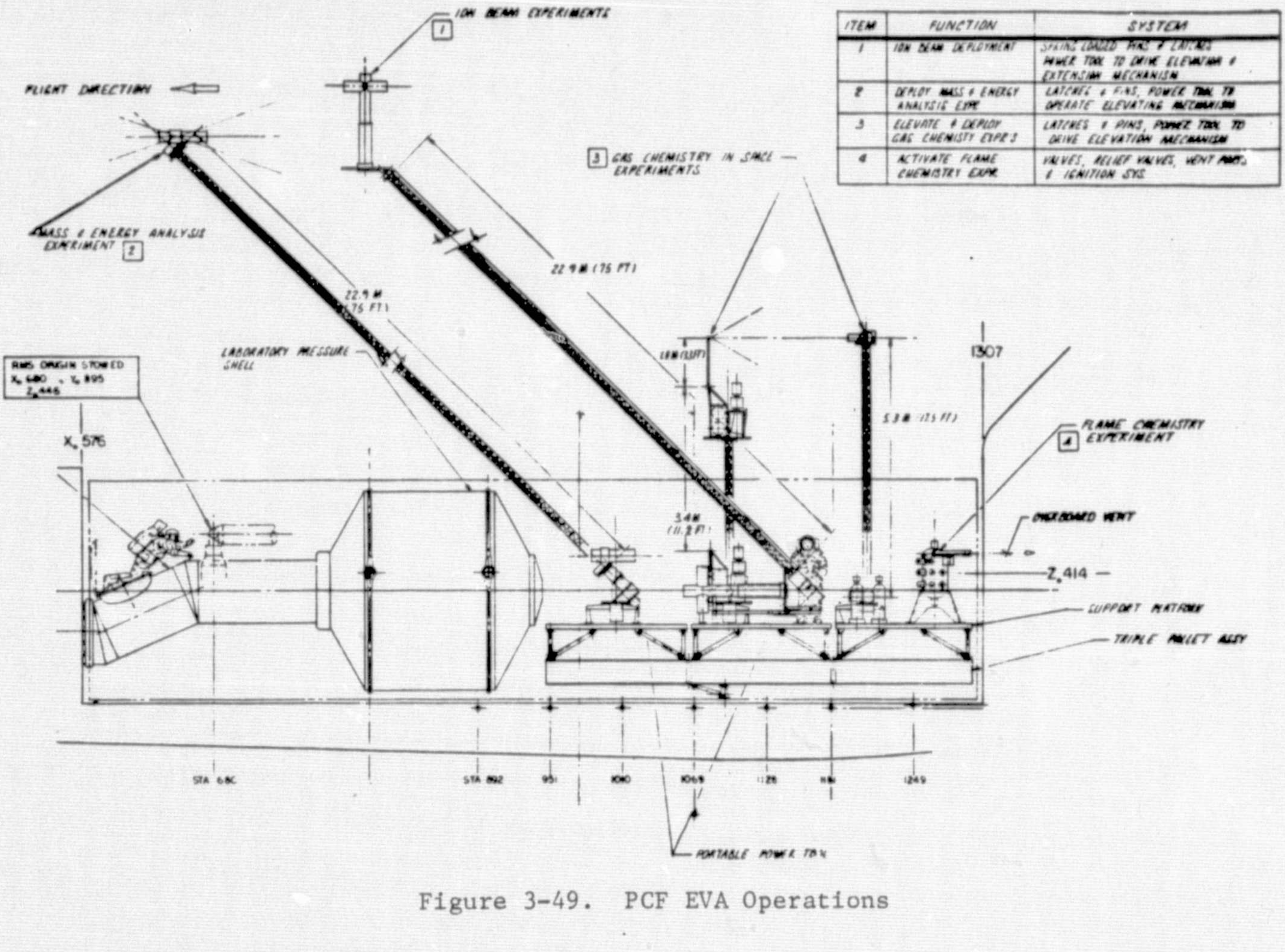
Flame Chemistry. The flame chemistry equipment installation is a miniversion of a pallet-mounted system. That is, the combustion chamber with circumferentially mounted sensors and attached oxidizer/fuel tanks are all palletized and placed in one of the Spacelab airlocks. The use of the airlock provides a degree of safety to the Spacelab crew plus eliminates the penetration requirement through the Spacelab to vent the combustion gases. This experiment along with gas chemistry in space will be performed in the latter part of the mission due to the type and quantity of contamination generated following each experiment iteration.

As for the experiments the use of the airlock provides access to the sensors and combustion chamber for purposes of changing film, cleaning and replacing sensors and replacing the combustables.

3.14.2 EVA Applications

Since application of EVA to the airlock operations described for the baseline configuration did not enhance the experiment, it was reasonable to consider reorganizing the payload by placing the equipment in permanent external locations, providing that sufficient volume for the necessary shirtsleeve operations was retained.

The Spacelab configuration was changed to the short module plus pallet. No experiment airlocks are needed since all the scientific equipment is pallet mounted allowing for total deployment on a single EVA and operation in any desired sequence (Figure 3-49).



ITEM	FUNCTION	SYSTEM
1	ION BEAM DEPLOYMENT	SPRING LOADED PINS & LATCHES POWER TOOL TO DRIVE ELEVATION & EXTENSION MECHANISM
2	DEPLOY MASS & ENERGY ANALYSIS EXPR	LATCHES & PINS, POWER TOOL TO OPERATE ELEVATING MECHANISM
3	ELEVATE & DEPLOY GAS CHEMISTRY EXPR'S	LATCHES & PINS, POWER TOOL TO DRIVE ELEVATION MECHANISM
4	ACTIVATE FLAME CHEMISTRY EXPR	VALVES, RELIEF VALVES, VENT PORTS & IGNITION SYS

Figure 3-49. PCF EVA Operations

Placing the equipment on the pallet eliminates the requirement to replace atmospheric gas loss due to each airlock operation; and allows the equipment to out-gas during a single operation without being recontaminated during subsequent airlock operations. Other item changes include the reduction of the number of deployable Astromast-type booms; simplification in deployment devices by replacement of deployable masts with manually erected pole-type masts; and the requirement to store hazardous materials within the Spacelab.

As each of the experiment sensor units are deployed and the EVA crewman moves about to the next work station, the experiment operator in the Spacelab begins to perform the checkout of each item. This allows all the units to be prepared during a single EVA including any adjustments found to be required during the checkout.

The only other EVA requirements are planned maintenance, contingencies and preparation for entry. These appear to require minimal EVA activity within the exception of the contingency mode which is the most unpredictable.

In the EVA-oriented design a single astronaut is capable of deploying all the experiment equipment at a single egress. Typically this could be done as shown in Figure 3-49 by egressing from the manned airlock and moving sequentially from equipment to equipment.

Mass and Energy Analysis Experiment. The same sensor unit as described in the baseline configuration is used in the EVA mode. The exception is that the sensor unit is pallet-mounted and has contamination covers at appropriate orifices. The EVA astronaut removes and stows the covers and extends the astromast device via a hand-held power tool. The experiment is operated in the same fashion as the baseline. After a successful deployment and systems check, the astronaut then translates to the next station.

Ion Beam Experiment. The sensor unit is mounted on the pallet behind the mass and energy analysis equipment. Here, the sensor unit is rotated horizontally during launch and entry to reduce excessive loading on the sensor itself and its mounting. Having removed all contamination covers, the EVA crewman unlatches the boost latches and attaches the sensor unit to the astromast making all pertinent connections. Using a hand-held power drive system, he extends the Astromast to its prescribed length locking it in place.

Gas Chemistry Experiments in Space. The two sensor platforms remain basically unchanged from that of the baseline. During the EVA preparation period the astronaut removes and stows all sensor contamination covers, inspects the sensors and platforms, and erects the booms by rotating them upward.

As he is preparing the sensor units, he also performs a visual inspection of the equipment installing the appropriate gas bottles as required and erecting the spray nozzle.

Flame Chemistry Experiment. The flame chemistry combustion chamber has also been firmly mounted on the aft-most position on the pallet. During the pre-operation phase, the astronaut prepares the combustion chamber by installing the required sensors and cine cameras. He also installs a combustion gas over-board vent which is stowed on the pallet during launch and entry. The various fuels and oxidizers are stored in a mini tank farm near the combusion chamber manifolded together to the chamber. This particular installation appears to be substantially more reliable and safer than the baseline.

During the operational phase the EVA astronaut will clean window ports, sensor probes, replacing same and photographic film. The experiment itself is remotely controlled from the Spacelab.

3.14.3 Operations Analysis

Operations Cycle

The first-level operations cycle block diagram for the PCF is shown in Figure 3-2. The figure shows a single continuous flow which is applicable for either baseline or EVA operations. Although a substantial change was affected to the EVA configuration, the general operations cycle remains fixed. The baseline configuration was not suitable for a direct EVA application, consequently it was felt that to place all the internally stowed but externally operated items on the pallet itself would reduce the continuous airlock activity, operational time loss, gas losses, and increase the effectivity of both the experiment equipment and astronaut utilization.

Sequence Comparisons

The overall approach used in the baseline sequence was to deliver all the scientific equipment to orbit stowed in a dual-section Spacelab. Once in orbit, the experiments will be serially deployed through the various airlocks of the Spacelab and operated in the space environment. As each experiment operation is performed, the astronaut may obtain access to the equipment by recalling the equipment into the airlocks and physically perform the necessary functions.

Since the number of airlocks is limited, and two of the experiments are affected by contaminants, the baseline configuration is limited to serial experiment operation. In addition, substantial automation is required to support the experiments due to the external operating location.

A direct application of EVA to the baseline configuration was unrealistic. A review of the experiments, equipment, and the Spacelab indicated a need for a better arrangement. Consequently, the Spacelab was changed to a single-section module and a pallet was added to support the equipment. The special airlock (ion beam experiment) was deleted.

With all the sensor and experiment equipment mounted on the pallet, the EVA astronaut is able to deploy all the sensor equipment on a single EVA. Two of the experiments, ion beam and mass and energy analysis experiments, may be operated together providing a synergistic effect whereas in the baseline mode dual operation was dependent upon availability of an airlock in the Spacelab.

The EVA mode provides a substantially simpler interface problem allowing for a more readily responsive and flexible experiment program. The task sequences are given in Table 3-15.

Timeline Comparisons

A true timeline comparison for this payload is rather difficult since there is such a gross dissimilarity between the baseline and EVA configurations (see Figures 3-50 and 3-51).

Table 3-15.
PHYSICS AND CHEMISTRY FACILITY
ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
1. PRE-OPERATIONS			
		Proceed to work station	Spacelab C&D area Handholds, foot restraints, work platforms
ION BEAM EXPERIMENT			
1.1 REMOVE CONTAMINATION SHIELD			
Depressurize ion beam airlock	Airlock vent valve	Basic sequences	
Command airlock hatch to unlatch and open	Airlock latches and hatch		
1.3.4 ERECT MECHANISMS			
Command experiment equipment to extend out of the airlock	Sensor/boom retract mechanism	Manually withdraw experiment system and lock into position	Sensor/boom system, boom latches
Command sensor mechanism to position in the operational configuration	Sun erection motor	Position and lock in place sensor mechanism atop the boom	Manually position sensor unit, locks
Command deployment of sensor boom	C&D panel, boom deployment mechanism	Manually deploy boom to operational position	Hand-held power drive tool, boom, boom locks
1.8 TEST AND CHECKOUT			
Basic sequences			
MASS AND ENERGY ANALYSIS OF NEUTRAL SPECIES			
1.7 INSTALL INSTRUMENTS			
Unstow experiment equipment and mount into the Spacelab airlock	Manually unstow in Spacelab, experiment airlock		
1.1 REMOVE CONTAMINATION SHIELD			
Depressurize airlock, unlatch and open airlock	Airlock vent, latches and hatch	Remove contamination covers	Manually remove/stow contamination covers
1.3.4 EXTEND MECHANISM			
Deploy airlock boom	Airlock boom drive mechanism	Unstow sensor mechanism and boom	Manually unlatch sensor unit latches, boom latches
Command positioning of sensor mechanism to its operational position	Sensor positioning device, latches	Deploy sensor/boom	Hand-held power drive tool, boom
Command extension of sensor boom to its operational length	Sensor boom drive mechanism		
1.8 TEST AND CHECKOUT			
Basic sequences			

Table 3-15. (continued)

PHYSICS AND CHEMISTRY FACILITY

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Automated	Payload Functional Reqmts.
GAS CHEMISTRY EXPERIMENT IN SPACE			
		1.1 REMOVE CONTAMINATION SHIELD	
		Remove contamination covers and stow	Contamination covers, latches and stowage device
1.7 INSTALL INSTRUMENTS			
Unstow sensor/platforms and attach to sensor booms	Stowage racks, sensor booms and fittings	Unstow booms and experiment platforms and secure together	Booms, experiment platforms, and latches
Mount into Spacelab airlocks	Airlock, airlock mount	Erect spray nozzle	Experiment equipment
Close airlock inner hatches, depressurize airlocks and unlatch and open external hatches	Airlock vent valves, latches and external hatches		
1.3.4 EXTEND MECHANISM			
Extend both booms to their normal operating positions	Boom drives and booms	Erect sensors and booms to operational position	Experiment equipment
1.8 TEST AND CHECKOUT			
Basic sequences			
FLAME CHEMISTRY			
1.7 INSTALL INSTRUMENTS			
Unstow combustion chamber and fuel tanks & install in airlock	Stowage mechanism, experiment equipment, airlock, airlock fixture	Vent combustion chamber	Manual vent system
Close airlock inner hatch and depressurize airlock	Airlock hatches and vent system	Attach appropriate sensors about chamber--manually	Supporting scientific sensors
Command opening of outer airlock hatch	Outer airlock hatch, latches	Connect combustion chamber and fuel/oxidizer tanks	Fuel/oxidizer disconnect/fittings
1.5 LOAD FILM			
Load film while equipment in Spacelab environment	Film cassettes	Load film and install camera on combustion chamber	Film cassettes
1.8 TEST AND CHECKOUT			
Basic sequences			
2. EXPERIMENT OPERATIONS			
ION BEAM EXPERIMENT			
This experiment is deployed and is allowed to monitor the surrounding atmosphere. Experimenter monitors data and may readjust boom deployment length or readjust sensors remotely as required from the C&D panels.			
2.9 ADJUST BOOM LENGTHS			
Adjust boom lengths per experiment schedule	PSS boom motor drive units	Manually adjust deployment length of the boom	Hand-held power drive tool and boom deployment mechanism

Table 3-15. (continued)

PHYSICS AND CHEMISTRY FACILITY

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
MASS AND ENERGY ANALYSIS OF NEUTRAL SPECIES			
Experiment is generally operated in the automatic mode with the exception of boom length changes and sensor mechanism attack angle, all remotely controlled from the control console.			
2.9 ADJUST BOOM LENGTHS			
Adjust boom length per experiment schedule	PSS, boom motor drive unit	Manually vary the length of the sensor boom	Hand-held power drive tool & boom deployment mechanism
2.10 ADJUST SENSOR EQUIPMENT			
Adjust angle of attack of sensor mechanism	PSS, sensor equipment	Manually vary the angle of attach of the sensor mechanism	Manual control on equipment
Adjust gas flow rate	PSS, sensor equipment	Manually vary the flow rate of gas subject to ionization	Manual control on equipment
GAS CHEMISTRY IN SPACE			
Perform experiment per operational procedure. Once the fluid is chosen, the nozzle sprays forth and the sensors automatically scan the cloud. All selection functions are performed remotely from the control panel.		**2.13 EXCHANGE EXPENDABLES**	
		Exchange gas bottles as required throughout the expmt.	Experiment boom, gas bottles
		2.10 ADJUST SENSOR EQUIPMENT	
		Adjust nozzle spray as required	Spray nozzle control, sensor boom
		Adjust secondary sensor boom as required	Experiment equipment
		2.11 CLEAN EXPERIMENT EQUIPMENT	
		Clean sensor surfaces and other items which may influence the data	Experiment equipment
FLAME CHEMISTRY			
The experiment once set in motion is automatically sequenced and data recorded.		**2.11 CLEAN EXPERIMENT EQUIPMENT**	
		Clean inner surfaces of combustion chamber and observation ports	Experiment equipment
2.7 OPERATE VALVES		**2.6 CHANGE FILM**	
Evacuate chamber of spent gas	Vent valve, purge system	Remove/replace photographic film	Film cassette
2.11 CLEAN EXPERIMENT EQUIPMENT			
Close external hatch on airlock; pressurize and open inner airlock hatch	Airlock hatch, hatch locks, pressurization system, inner airlock hatch & latches		
Remove combustion chamber, clean inner surfaces, and observation ports and replace film and gas	Combustion chamber, sensors, cine camera, and combustible gas		

Table 3-15. (continued)

PHYSICS AND CHEMISTRY FACILITY

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
2.12 REDEPLOY EXPERIMENT EQUIPMENT			
Reinstall combustion chamber in airlock and redeploy	Airlock hatch, hatck locks, pressurization system, inner airlock hatch and latches		
3. CONTINGENCY OPERATIONS			
ION BEAM EXPERIMENT			
3.1 RELEASE/OPERATE JAMMED MECHANISM			
Basic sequences			
3.2 RELEASE FAILED EXTENDIBLE		3.3 DISABLE POWER/SIGNAL PATHS	
Basic sequences		Basic sequences	
3.3 DISABLE POWER/SIGNAL PATHS		3.2 RELEASE FAILED EXTENDIBLES	
Basic sequences		Basic sequences	
MASS AND ENERGY ANALYSIS OF NEUTRAL SPECIES			
3.1 RELEASE/OPERATE JAMMED MECHANISM			
Remotely command each boom to extend/retract to release the jamming	Boom drive system and C&D panels	Release source of jamming	As required
Pulse sensor mechanism to change angle of attack	Sensor unit positioning mechanism	Manually articulate sensor mechanism to free jamming	As required, handholds, foot restraints
Pulse separate controls as required to release stoppages/jammings	C&D panel and experiment equipment	Manually adjust ionizing gas flows	Experiment equipment
		Modify equipment to continue experiment	As required
3.2 RELEASE FAILED EXTENDIBLE			
Basic sequences			
3.3 DISABLE POWER/SIGNAL PATHS			
Disable power/data paths	C&D panel		
GAS CHEMISTRY IN SPACE			
3.1 RELEASE/OPERATE JAMMED MECHANISM			
Basic sequences			
3.7 TROUBLESHOOTING			
Recover experiment equipment and troubleshoot/repair in Spacelab	Experiment equipment	Troubleshoot/inspect equipment	Experiment equipment
3.6 MECHANISM REPAIR			
Basic sequences			

Table 3-15. (continued)

PHYSICS AND CHEMISTRY FACILITY

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
3.2 JETTISON FAILED MECHANISM			
Basic sequences			
FLAME CHEMISTRY			
3.9 PREPARE EQUIPMENT FOR PRESSURIZED AREA			
Evacuate chamber and purge if gases fail to ignite	Vent system	Manually vent gases if auto-valve fails	Vent system
Recover equipment into spacelab and troubleshoot	Airlock		
3.6 MECHANISM REPAIR			
Repair/modify as required	Experiment equipment	Repair as necessary	Experiment equipment
3.2 JETTISON FAILED EQUIPMENT			
Basic sequences			
6. PLANNED MAINTENANCE			
ION BEAM EXPERIMENT			
6.3 INSPECT EXPERIMENT EQUIPMENT			
Inspect via TV the deployment boom and external condition of sensor mechanism	CCTV and RMS	Visually inspect as much of the mechanism as possible	Visual inspection
6.10 RETURN EQUIPMENT TO PRESSURIZED AREA		6.5 REMOVE AND REPLACE	
Retract sensor/boom into airlock; perform maintenance in spacelab environment	Airlock, boom system, appropriate maintenance	Manually retract boom to access fail/damage sensor	Hand-held power drive tool, tool kit
		Manually remove/replace failed/damaged item	Experiment equipment, spares, tool kit
6.11 CALIBRATE EXPERIMENT EQUIPMENT			
Remove, replace, and calibrate sensor items	Experiment equipment, calibration equipment		
6.7 CLEAN SENSORS			
Clean sensor mechanism as required	Experiment equipment, equipment cleaner	Clean sensor mechanism as required	Experiment equipment, equipment cleaner
6.8 REPAIR MECHANISMS			
Repair mechanisms as required	Experiment equipment, repair kit	Repair repairable items in situ	Experiment equipment, repair kit
MASS AND ENERGY ANALYSIS OF NEUTRAL SPECIES			
6.3 INSPECT EXPERIMENT EQUIPMENT			
Inspect deployed equipment via TV	CCTV and RMS	Visually inspect deployed unit(s)	Visual inspection

Table 3-15. (continued)
PHYSICS AND CHEMISTRY FACILITY

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	**Payload Functional Reqmts.**	**Sequence**	**Payload Functional Reqmts.**
6.10 RETURN EQUIPMENT TO PRESSURIZED AREA			
Retract sensor/booms into airlock and into the spacelab; access to sensors	Airlock, booms, appropriate maintenance		
6.5 REMOVE AND REPLACE			
Remove and replace failed/damaged item		Manually retract boom for access to sensor mechanism	Hand-held power drive tool, boom retract system
Exchange/refill ionizing gases	Gas tank system	Exchange/refill ionizing gases	Gas tank system
		Manually remove/replace failed/damaged items	Experiment equipment and tools
6.7 CLEAN SENSORS			
Clean sensor mechanism as required	Experiment equipment and cleaning unit	Clean sensor mechanism as required	Experiment equipment and cleaning unit
6.8 REPAIR MECHANISM			
Repair mechanical item as permitted	Experiment equipment and tools	Repair mechanical items as permitted	
GAS CHEMISTRY IN SPACE			
6.3 INSPECT EXPERIMENT EQUIPMENT			
Inspect both deployed sensor/boom units via TV	CCTV and RMS	Inspect experiment installation visually	Visual inspection
6.10 RETURN EQUIPMENT TO PRESSURIZED AREA			
Retract both booms and sensor platforms into airlock and into spacelab, access to sensor	Airlocks, booms, sensor platforms and C&D panel		
6.5 REMOVE AND REPLACE			
Remove and replace damaged/failed items	Experiment equipment and tools	Retract booms as required to obtain access to sensors	Booms and sensor platforms
		Remove/replace damaged/failed items	Experiment equipment and tools
6.9 SERVICE OTHER FLUIDS			
Exchange/refill gas bottles expended during experiment	Gas bottle system and spares	Exchange/refill gas bottles expended during the experiment	Gas bottle system
6.7 CLEAN SENSORS			
Change spray nozzle (or clean) as required	Spray nozzle and tools	Change spray nozzle (or clean) as required	Spray nozzle and tools
Clean sensor/sensor optics as required	Exoeriment equipment and cleaning unit	Clean sensor/sensor optics as required	Experiment equipment and cleaning unit
6.8 REPAIR MECHANICAL ITEMS			
Repair mechanical items	Experiment equipment & tools	Repair mechanical items in situ	Experiment equipment & tools

TABLE 3-15.

PHYSICS AND CHEMISTRY FACILITY

ACTIVITY SEQUENCES FOR BASELINE AND EVA SERVICED PAYLOADS

AUTOMATED		EVA	
Sequence	Payload Functional Reqmts.	Sequence	Payload Functional Reqmts.
FLAME CHEMISTRY			
6.3 INSPECT EXPERIMENT EQUIPMENT			
Inspect combustion chamber installed via TV	CCTV and RMS	Visually inspect combustion chamber	Visual inspection
6.10 RETURN EQUIPMENT TO PRESSURIZED AREA			
Withdraw chamber from airlock into spacelab	Airlock, latches, pressurization system, and experiment equipment		
6.7 CLEAN SENSORS			
Clean inner/outer surfaces of combustion chamber	Experiment equipment and cleaning unit	Clean inner/outer surfaces combustion chamber	Experiment equipment, tools and cleaning unit
6.5 REMOVE AND REPLACE			
Remove/replace damaged sensors	Experiment equipment	Remove/replace damaged/failed sensors in situ	Experiment equipment, tools and spares
6.8 REPAIR MECHANICAL ITEMS			
Repair, as required, damaged/failed components of combustion chamber	Experiment equipment, tools and spares		
6.9 SERVICE OTHER FLUIDS			
Service fluid system as required	Experiment equipment and fluids	Replace fluid tanks as required	Experiment equipment and fluids
7. PREPARE FOR RETURN			
Inverse of 1. Pre-Operations		Inverse of 1. Pre-Operations	

In the baseline mode, each payload is separately deployed and operated. Therefore, a separate start time is indicated for each experiment equipment set. In the EVA mode, the newly suggested configuration is totally oriented toward EVA.

It is noted that in the baseline mode the ion beam and the mass and energy analysis of neutral species may and probably should be deployed at about the same time to allow parallel operations and correlative data taking. In the EVA mode, depending upon the local conditions, these same two experiments may be operated during the flame chemistry and gas chemistry experiments; i.e., all four at once. Servicing and refurbishment may be performed at any time during the mission with minimal interruption to both the experiment procedures.

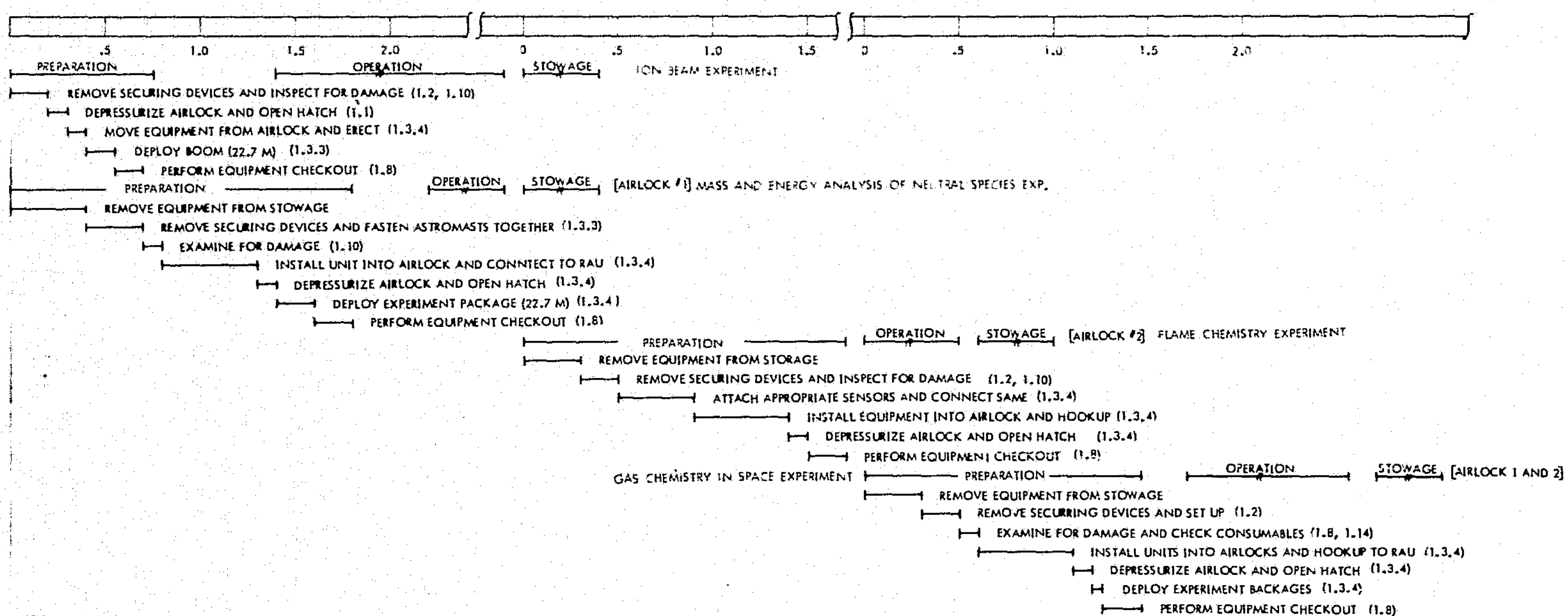


Figure 3-50. PCF - Preparation for Operation, Baseline Mode

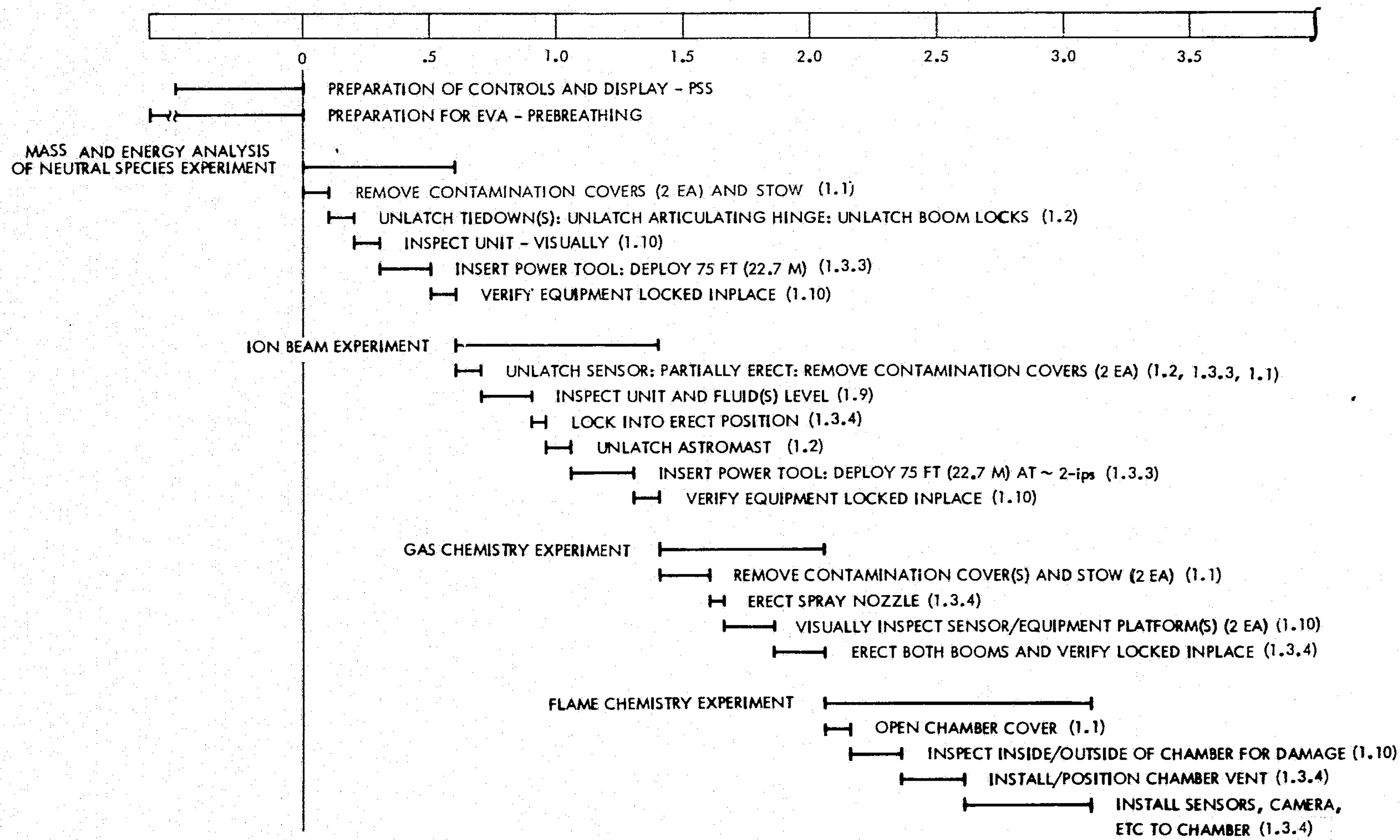


Figure 3-51. PCF - Preparation for Operation, EVA Mode

IV. COMPARATIVE ANALYSIS AND PROGRAM EXTRAPOLATION

4.1 COSTING ANALYSIS

Costs in the study were developed for flight hardware and related program costs associated with routine operations, planned maintenance, and contingencies. In addition, Shuttle transportation cost data were used in comparing maintenance and contingency options. The method used for deriving hardware and program costs is presented with particular definition as to how comparative costs were developed for establishing the impact of EVA routine operations on each representative payload. This section also describes how program modeling was performed and how representative payload cost comparisons were then extrapolated. While the methods for hardware cost data were the same for the maintenance and contingency analyses, these data were applied somewhat differently, and are described in the next section.

4.1.1 Work Breakdown Structure (WBS)

A generic WBS with sufficient flexibility to accommodate a wide variety of representative payloads was established based along classical lines. The importance of having a standardized subdivision of program elements for control purposes early can be realized when one considers the amount of in-depth investigation, technical analyses, and costing required for the variety of EVA-oriented approaches. Also, the establishment of a uniform structure of EVA impact areas was considered essential to the achievement of meaningful evaluations and comparisons of EVA payoffs. Figure 4-1 reflects the preliminary generic WBS.

The generic WBS is structured in such a manner as to depict the program elements of baseline payload concepts and the realignment or modification of program elements resulting from the application of a recommended EVA approach. Using the generic WBS as a guide, specific WBS elements were prepared for each of the 13 representative payloads. The first step was to construct a WBS as it applies to the specific conventional payload concept reflecting only those payload subsystems, experiments, mission equipment, and support items required by the particular payload. Figure 4-2 illustrates a more detailed WBS for flight hardware.

Based upon results of the engineering technical analyses, each baseline payload WBS was modified to reflect the impact of EVA applications. This WBS reflects three major categories of WBS elements, elements with items deleted or modified by EVA, common WBS elements or items unaffected by EVA, and elements with items added or modified by EVA application. The WBS items deleted and items added or modified by EVA were expanded to a lower level of detail sufficient to reflect the components or assemblies deleted, modified, or added. Where it was determined that EVA had no impact within a WBS element, or when the impact was considered to be minor, no lower levels of detail were identified below the box shown on the conventional WBS.

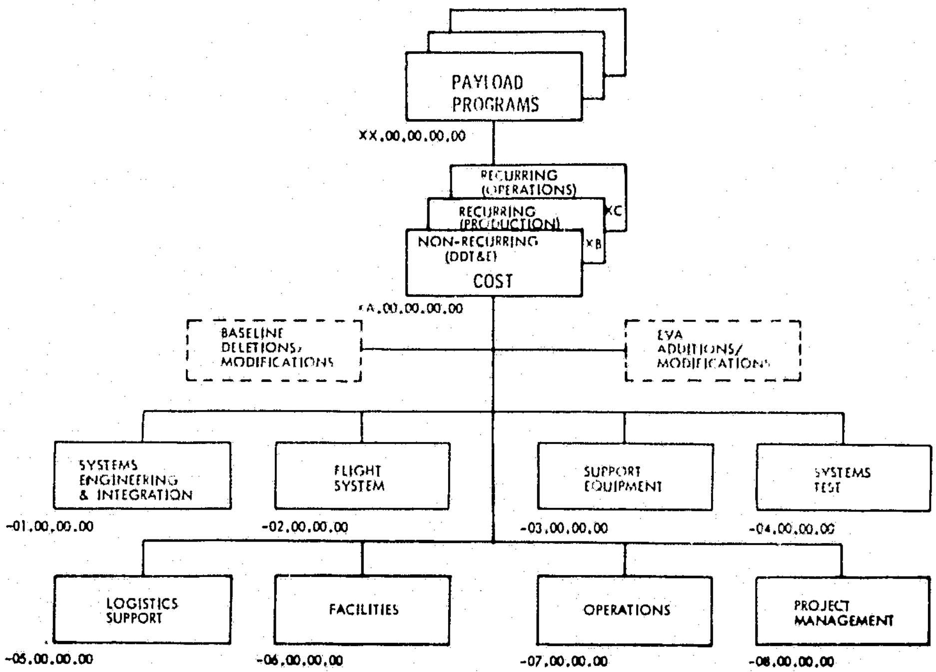


Figure 4-1. Preliminary Work Breakdown Structure Approach

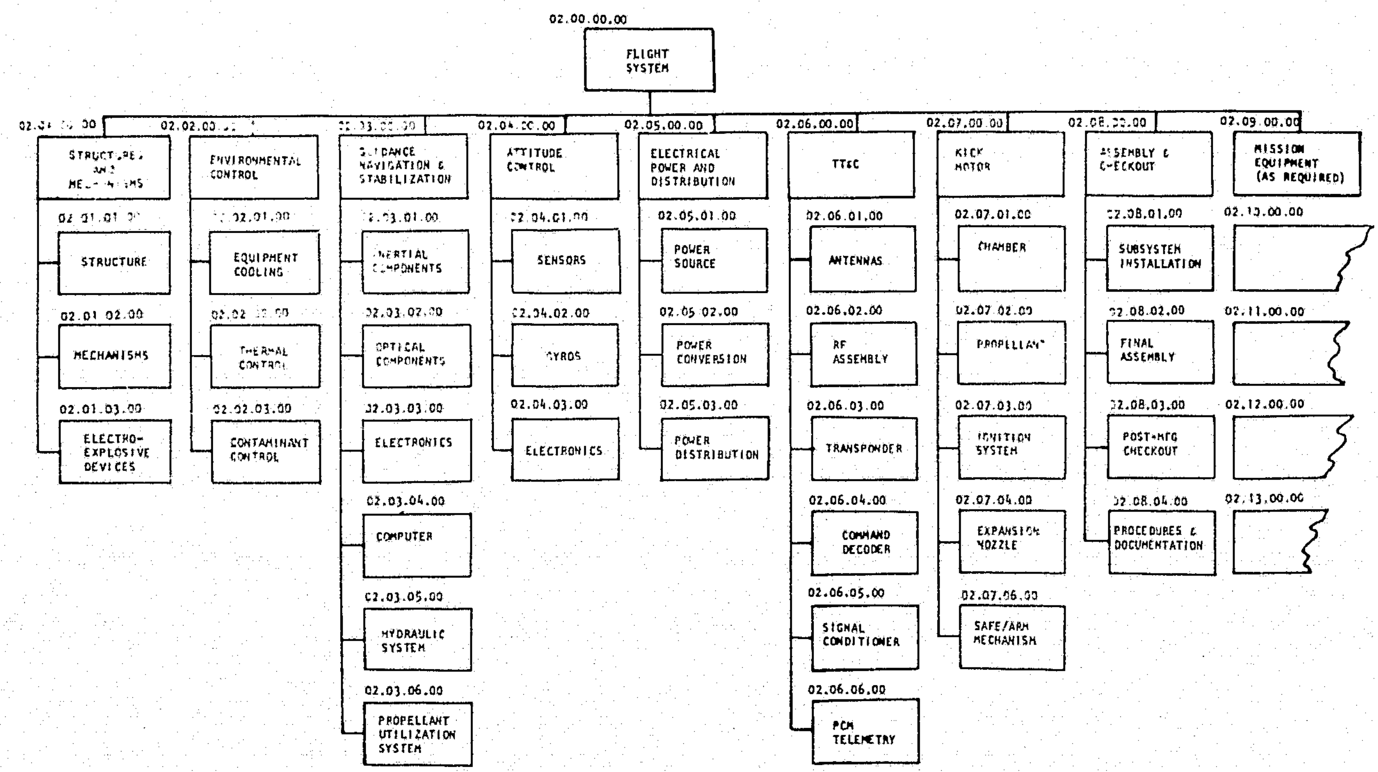


Figure 4-2. Flight Hardware WBS

The following listing constitutes a complete indentured WBS. Table 4-1, and a descriptive WBS dictionary, Table 4-2.

Table 4-1. EVA Study Generic Work Breakdown Structure

WBS Number	Item Name
XX.00.00.00.00	PAYLOAD PROGRAM
01.0.0.0	SYSTEMS ENGINEERING & INTEGRATION
1.0.0	SYSTEM ANALYSIS
2.0.0	SYSTEM INTEGRATION
3.0.0	INTERFACE CONTROL
4.0.0	SYSTEM SAFETY
5.0.0	RELIABILITY/MAINTAINABILITY
6.0.0	SOFTWARE DEVELOPMENT
7.0.0	SYSTEM DOCUMENTATION
02.0.0.0	FLIGHT SYSTEM
1.0.0	STRUCTURES & MECHANISMS
1.0	STRUCTURES
2.0	MECHANISMS
3.0	ELECTROEXPLOSIVE DEVICES
2.0.0	ENVIRONMENTAL CONTROL
1.0	EQUIPMENT COOLING
2.0	THERMAL CONTROL
3.0	CONTAMINANT CONTROL
3.0.0	GUIDANCE, NAVIGATION & STABILIZATION
1.0	INERTIAL COMPONENTS
2.0	OPTICAL COMPONENTS
3.0	ELECTRONICS
4.0	COMPUTER
5.0	HYDRAULIC SYSTEM
6.0	PROPELLANT UTILIZATION SYSTEM
4.0.0	ATTITUDE CONTROL
1.0	SENSORS
2.0	GYROS
3.0	ELECTRONICS
5.0.0	ELECTRICAL POWER & DISTRIBUTION
1.0	POWER SOURCE
2.0	POWER CONVERSION
3.0	POWER DISTRIBUTION
6.0.0	TT&C
1.0	ANTENNAS
2.0	R.F. ASSEMBLY
3.0	TRANSPONDER
4.0	COMMAND DECODER
5.0	SIGNAL CONDITIONER
6.0	PCM TELEMETRY

Table 4-1. EVA Study Generic Work Breakdown Structure (Cont.)

7.0.0	KICK MOTOR
1.0	CHAMBER
2.0	PROPELLANT
3.0	IGNITION SYSTEM
4.0	EXPANSION NOZZLE
5.0	SAFE/ARM MECHANISM
8.0.0	ASSEMBLY & CHECKOUT
1.0	SUBSYSTEM & MISSION EQUIPMENT INSTALLATION
2.0	FINAL ASSEMBLY
3.0	POST-MANUFACTURING CHECKOUT
4.0	PROCEDURES & DOCUMENTATION
X.0.0	MISSION EQUIPMENT
03.0.0.0	SUPPORT EQUIPMENT
1.0.0	GROUND SUPPORT EQUIPMENT
1.0	MECHANICAL SUPPORT EQUIPMENT
2.0	ELECTRICAL SUPPORT EQUIPMENT
3.0	GROUND HANDLING EQUIPMENT
2.0.0	ORBITAL SUPPORT UNIT
04.0.0.0	SYSTEMS TEST
1.0.0	SYSTEM DEVELOPMENT TEST
2.0.0	SYSTEM QUALIFICATION TEST
3.0.0	ACCEPTANCE TEST
05.0.0.0	LOGISTICS SUPPORT
1.0.0	TRANSPORTATION & HANDLING
2.0.0	INVENTORY CONTROL & WAREHOUSING
3.0.0	TRAINING
4.0.0	SPARES
5.0.0	SUPPORT DOCUMENTATION
06.0.0.0	FACILITIES
1.0.0	MANUFACTURING
2.0.0	TEST & INTEGRATION
3.0.0	LAUNCH
4.0.0	OPERATIONS
07.0.0.0	OPERATIONS
1.0.0	MISSION MANAGEMENT
1.0	MISSION CONTROL
2.0	SCIENCE COORDINATION
3.0	LAUNCH/LANDING MANAGEMENT
2.0.0	LAUNCH OPERATIONS
1.0	SITE ACTIVATION
2.0	PREFLIGHT ASSEMBLY & CHECKOUT
3.0	LAUNCH SUPPORT
3.0.0	FLIGHT OPERATIONS
1.0	ORBITAL OPERATIONS & CREW
2.0	OPERATIONS GROUND MONITORING
3.0	GROUND TARGET ACTIVITIES
4.0	GROUND LABORATORY SUPPORT

Table 4-1. EVA Study Generic Work Breakdown Structure (Cont.)

08.0.0.0	PROJECT MANAGEMENT
1.0.0	ENGINEERING ADMINISTRATION
2.0.0	BUSINESS MANAGEMENT
1.0	FINANCIAL MANAGEMENT
2.0	SCHEDULE MANAGEMENT
3.0	DATA MANAGEMENT
3.0.0	ASSURANCE MANAGEMENT
1.0	QUALITY CONTROL
2.0	CONFIGURATION MANAGEMENT
4.0.0	MATERIAL/SUBCONTRACT MANAGEMENT

Table 4-2. EVA Study Generic Program Work Breakdown Structure Dictionary

XX.00.00.00.00	PAYLOAD PROGRAM. This element on the generic work breakdown structure (WBS) is representative of the 13 payload systems to be analyzed for EVA application during the study. The element will become the top level element on the discrete WBS to be developed for each payload system.
01.0.0.0	SYSTEMS ENGINEERING AND INTEGRATION. The summarization of tasks and activities required to initiate, maintain and support a totally integrated engineering effort.
1.0.0	System Analysis. The analysis and definition of requirements for the design and operation of the integrated system. The element includes operations analysis, performance evaluation, mission analysis and planning, and analysis and definition of EMI, flight and ground, and test and checkout requirements.
2.0.0	System Integration. The establishment of system/subsystem/experiment design configuration. The element includes design analysis, stress/dynamics analysis, thermal analysis, mass properties, and GSE/subsystem interface control.
3.0.0	Interface Control. The definition of functional and physical interface requirements between the payload system and the spacecraft or launch vehicle. The design of interface hardware is included.
4.0.0	System Safety. The application of system safety criteria in all phases of system development and operation. Specifically included are hazard identification and categorization, determination of hazard credibility, and development of operational safety concepts.

Table 4-2.
EVA STUDY
GENERIC PROGRAM
WORK BREAKDOWN STRUCTURE DICTIONARY (Cont.)

5.0.0	Reliability/Maintainability. The definition of reliability goals, apportionment and prediction modeling, failure mode and effects analysis, reliability improvement design assessments, and reliability versus weight or cost trade studies. The element includes the analysis and definition of maintainability requirements.
6.0.0	Software Development. The assembly of requirements,development, and verification of system software. On-board, mission support, test, and GSE software are included.
7.0.0	System Documentation. The preparation of specifications, operational plans, test procedures and procurement documentation.
02.0.0.0	FLIGHT SYSTEM. The summarization of the installed subsystems and experiments comprising a flight payload system including the associated design, development, production, and assembly and checkout.
1.0.0	Structures and Mechanisms. The design, development, production and test of the system structure, mechanisms and electroexplosive devices. The structure (1.0) includes the basic structure, trusses, supports, mounts, and shielding. Mechanisms (2.0) include array and antenna deployment mechanisms, waveguides, separation switches and docking probes and latches. Electroexplosive devices (3.0) include those required for arrays, antennas and payload separation.
2.0.0	Environmental Control. The design, development, production and test of the assemblies and components required to maintain payload system design temperature limits, manage heat rejection of the subsystems, and control contamination within acceptable limits. WBS sub-element divisions include equipment cooling (1.0), thermal control (2.0), and contaminant control (3.0).
3.0.0	Guidance, Navigation and Stabilization. The design, development, production and test of the assemblies and components required for navigating, steering and maintaining the flight path of the payload system. Sub-elements consist of navigation and reaction control items including inertial components

Table 4-2.
EVA STUDY
GENERIC PROGRAM
WORK BREAKDOWN STRUCTURE DICTIONARY (Cont.)

	(1.0), optical components (2.0), electronics (3.0), computer (4.0), hydraulic system (5.0) and the propellant utilization system (6.0).
4.0.0	Attitude Control. The design, development, production and test of the assemblies and components required to maintain the attitude of the spacecraft with respect to a selected reference point or points. Sub-elements include sensors (1.0), gyros (2.0), and electronics (3.0).
5.0.0	Electrical Power and Distribution. The design, development, production and test of the equipment required to generate, store, control and distribute electrical power to the payload subsystems. Sub-elements include the power source (1.0) such as solar arrays and batteries; power conversion (2.0) to provide regulated power; and power distribution (3.0) including cabling between subsystems and between assemblies in subsystems.
6.0.0	TT&C. The design, development, production and test of the equipment required to receive, demodulate and execute commands, transmit data, and receive and transmit ranging signals. Sub-elements include antennas (1.0), R.F. assembly (2.0), transponder (3.0), command decoder (4.0), signal conditioner (5.0), and PCM telemetry (6.0).
7.0.0	Kick Motor. The design, development, production and test of the assemblies and components comprising a motor required for placing the payload system into final orbit following separation from the launch vehicle. Sub-elements include the chamber (1.0), propellant (2.0), ignition system (3.0), expansion nozzle (4.0), and the safe/arm mechanism (5.0).
8.0.0	Assembly and Checkout. The installation of subsystems and the assembly and checkout of the flight system as a unit. Sub-elements include subsystem and mission equipment installation (1.0), final assembly (2.0), post-manufacturing checkout (3.0), and procedures and documentation (4.0).
X.0.0	Mission Equipment. This element is representative of the various kinds of mission equipment which may be required for the different payload systems. The equipment required for each experiment group will appear on the WBS.
03.0.0.0	SUPPORT EQUIPMENT. The summarization of effort associated with providing the deliverable equipment required for delivery, maintenance, and checkout of the payload system and subsystems.

Table 4-2.
EVA STUDY
GENERIC PROGRAM
WORK BREAKDOWN STRUCTURE DICTIONARY (Cont.)

1.0.0	Ground Support Equipment. The design, development, production and test of equipment used on the ground to service, handle and test flight equipment. Sub-elements include mechanical support equipment (1.0), electrical support equipment (2.0), and ground handling equipment (3.0).
2.0.0	Orbital Support Unit. The design, development, production and test of the automated equipment required for launch, maintenance and checkout of the payload subsystems during orbital operations.
04.0.0.0	SYSTEMS TEST. The summarization of the effort supporting the system level test program. Testing which can be associated with a specific subsystem is included under that subsystem and not under systems test.
1.0.0	System Development Test. Testing conducted to confirm the feasibility of the design approach, demonstrate the advantage of one design over another, confirm analytical methods, or generate essential design data. Tests include those such as static and dynamic, thermal control, thermal vacuum, antenna, vibro-acoustic, separation and pyro shock.
2.0.0	System Qualification Test. Testing conducted utilizing a flight hardware test vehicle to demonstrate that design requirements have been achieved, and provide confidence that similar items manufactured under similar conditions can survive the expected service environments. Tests are similar to those of development test, except carried to higher load levels.
3.0.0	Acceptance Test. Testing required to verify that flight items are ready for delivery, comply with specifications, are free from defects, and capable of performing in conformance with contractual requirements. Acceptance tests include functional checkout of each subsystem, flight simulation tests, integration system tests and test documentation.
05.0.0.0	LOGISTICS SUPPORT. The summarization of the effort and activities required to move, provision, document, and provide training related to flight items and ground equipment.

Table 4-2.
EVA STUDY
GENERIC PROGRAM
WORK BREAKDOWN STRUCTURE DICTIONARY (Cont.)

1.0.0	Transportation and Handling. The transporting and handling of payload systems and support material in accordance with accepted government and contractor preservation specifications.
2.0.0	Inventory Control and Warehousing. The establishment of a warehousing function for the receipt, handling storage and accountability of material required for site operations. The element further includes the establishment of criteria for inventory management, and the identification of a closed-loop accounting system for inventory control of spare parts.
3.0.0	Training. The preparation and provision of familiarization training to customer personnel. Equipment, including training aids and accessories needed to support the training program, is included.
4.0.0	Spares. The identification and provision of components or assemblies required for replacement purposes in major end items of equipment.
5.0.0	Support Documentation, The preparation of field and operations documentation to support maintenance and spares provisioning of flight and ground support systems.
06.0.0.0	FACILITIES. The summarization of the effort related to identifying, providing and maintaining the facilities required to produce, test, launch and operate the payload system.
1.0.0	Manufacturing. The plant rearrangement necessary for the fabrication, assembly, in-process testing, and post-manufacturing checkout of flight and test items and support equipment.
2.0.0	Test. The provision of facilities (contractor or other) required to support the test program. Construction of facilities dedicated to testing of the payload system may be included.
3.0.0	Launch. The arrangement for and use of facilities at the launch site in support of the preparation and launch of the payload system.
4.0.0	Operations. The arrangement for and preparation of the facilities required to support the payload system during the operational phase.

Table 4-2.
EVA STUDY
GENERIC PROGRAM
WORK BREAKDOWN STRUCTURE DICTIONARY (Cont.)

07.0.0.0	OPERATIONS. Provide prelaunch, launch, post-launch and flight operations support including launch vehicle interface and test requirements.
1.0.0	LAUNCH SUPPORT. Provide technical support during prelaunch and launch operations including generation of test procedures, technical advice, evaluation of performance, on-spot changes to test requirements, investigation of anomalies, support to mission simulation and launch computer programs, and launch data review. Deactivation of associated equipment including spares and pertinent data records.
2.0.0	FLIGHT OPERATIONS. Provide technical advisory and support services during orbital operations to verify, analyze and report on normal and anomalous operations including supporting computer programs.
08.0.0.0	PROJECT MANAGEMENT. The summarization of the technical and business management activities associated with planning and controlling the definition, development, production, test and delivery of the payload system.
1.0.0	Engineering Administration. The planning, controlling and monitoring of engineering technical performance and products. Specific tasks include the development and control of engineering product schedules, definition and maintenance of the indentured breakdown list, and checking of engineering drawings.
2.0.0	Business Management. The project planning and control tasks associated with financial, schedule, and data management. Financial management (1.0) tasks include the implementation of a cost control system, integrated cost/schedule analysis, and cost performance reporting. Schedule management (2.0) tasks include project schedule preparation, maintenance and monitoring, and coordination of project reviews and meetings. Data management (3.0) tasks include the coordination, processing and delivery of prime and subcontract data items.

Table 4-2.
EVA STUDY
GENERIC PROGRAM
WORK BREAKDOWN STRUCTURE DICTIONARY (Cont.)

3.0.0	Assurance Mangement. The planning and control tasks associated with quality control and configuration management. Quality control (1.0) tasks include the preparation of a quality program plan and management support of all aspects of the plan including resource planning, implementation, monitoring, quality engineering, and procurement quality assurance. Line inspection is included under the subsystem hardware elements and is excluded from this element. Configuration management (2.0) tasks include providing a systematic process for establishing and implementing baseline identification, change control, interface control, and verification and accounting for the as-built/as-designed configuration of hardware and software.
4.0.0	Material/Subcontract Management. The effort required to subcontract, purchase and administer services, raw materials, hardware, parts, and equipment.

4.1.2 Cost Data Development

The following ground rules were utilized in developing cost estimates: (1) all costs are normalized to 1974 dollars, (2) profit or fee is excluded, and (3) launch vehicle and launch costs are excluded.

Cost data were developed from a variety of sources including current and past in-house and outside studies, past program history of both manned and unmanned spacecraft, payloads and boosters, vendor quotations and, where appropriate, detail estimates.

In-house studies and hardware programs have been developed into cost estimating relationships (CER's) for flight hardware DDT&E and unit costs. Associated costs such as Ground Support Equipment, System Engineering and Integration, System Test, Program Management, and other applicable data for specific projects have been calculated as percentages of flight hardware. This material formed the basis for the majority of costs generated on the present study and was utilized to determine base CER's, weight scaling slopes, and other cost factors.

The data and methodology are the same as were used for the Space Shuttle contract and recent military satellite firm price quotations. Complete information is proprietary and is, therefore, not furnished in this general circulation report.

The CER's to be used for the representative payload cost estimates were determined by analyzing the subystem costs for five unmanned satellites or payloads on which Space Division either submitted firm price quotations or won contracts (P72-2, ELMS, SEPS, GPS, and SEASAT). Weight and cost for both DDT&E and recurring first-unit cost were extracted from the data bank. Figure 4-3 illustrates the basic relationship of these data in the overall study costing. The cost was normalized to 1974 dollars, the pound weight converted to kilograms, and plotted to establish the CER trend. A line of best fit was visually drawn through the plot points and these data used as the basis for weight scaling the various selected payloads. Figures 4-4 and 4-5 depict typical slopes derived in this manner.

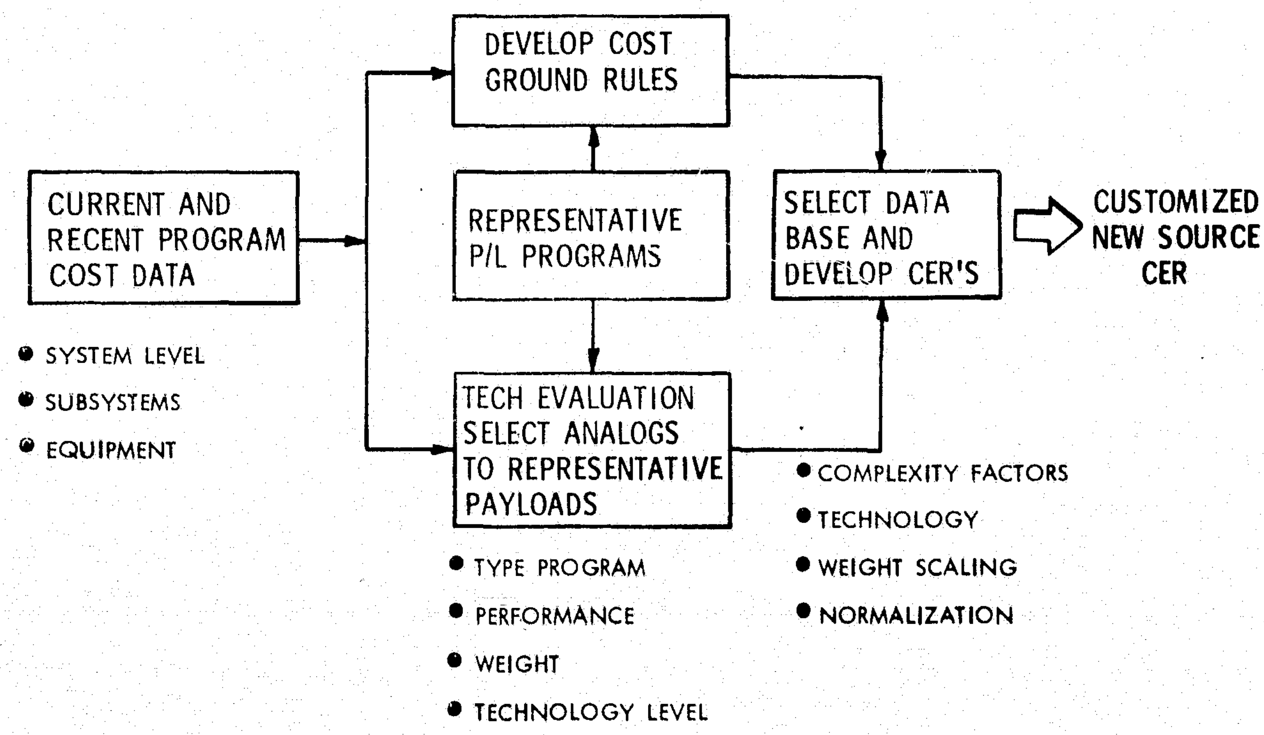


Figure 4-3. CER Costing Methodology

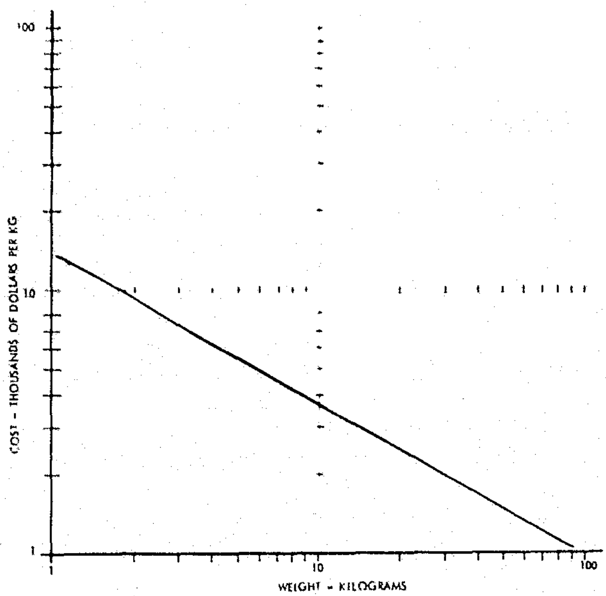


Figure 4-4. TT&C DDT&E Costs

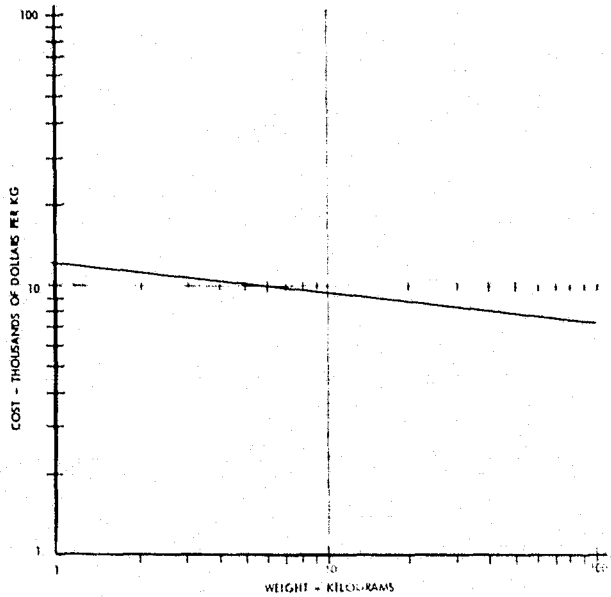


Figure 4-5. TT&C Recurring (First-Unit Cost)

Other costs such as Systems Engineering and Integration, Ground Support Equipment, Systems Test, Logistics Support, Facilities, Operations and Program Management, were factored into the total cost based on their relationship to Flight hardware (subsystem and mission equipment) cost. Orbital Support Equipment was costed on the basis of recently studied similar equipment for Flight Support systems.

Where applicable and especially in the Mission Equipment area, data from other recent NASA-funded studies, vendor quotes and engineering estimates were used to cost specific hardware. The data were converted to CER's and the same technique of weight scaling and application of complexity factors was utilized as described for the subsystem CER's.

4.1.3 Representative Payload Costing Analysis

The major objective of the representative payloads analysis was to develop program cost comparison data where EVA-oriented payload design could provide practical alternatives to presently planned automated designs.

The starting point for the analyses of the 13 selected representative payloads was the review of source data to establish mission objectives and requirements. These were then summarized in payload configuration definitions and operational flows. From these the potential EVA applications were identified. Detailed designs and operations data were developed to support the EVA and baseline payloads in terms of weight and complexity. When required, the existing baseline designs were developed in greater detail.

Reference data for the representative payloads were extracted from such studies as the Shuttle System Payload Definition (SSPD), Tracking and Data Relay Satellite (TDRS), Shuttle Infrared Telescope Facility (SIRTF), and others. Based on analyses of operational flows and the payload configuration definition, complete overall design definitions were produced in the form of engineering drawings. Data were continuously exchanged during the payload configuration definition phase and the design layout phase. Particular attention was given to detail design requirements involving EVA applications.

Design Analysis

An example of such detail design analysis is shown in analyzing EVA applications to the Magnetic Field Monitor. The Magnetic Field Monitor (MFM) satellite, identified as MAGSAT, is described as a low-cost modular design illustrated in Figure 4-6. The exploded view is used to show the evaluation that was performed on the baseline design, in order to establish where EVA alternatives exist. These are identified by an asterisk next to the item. Guidance sensors,

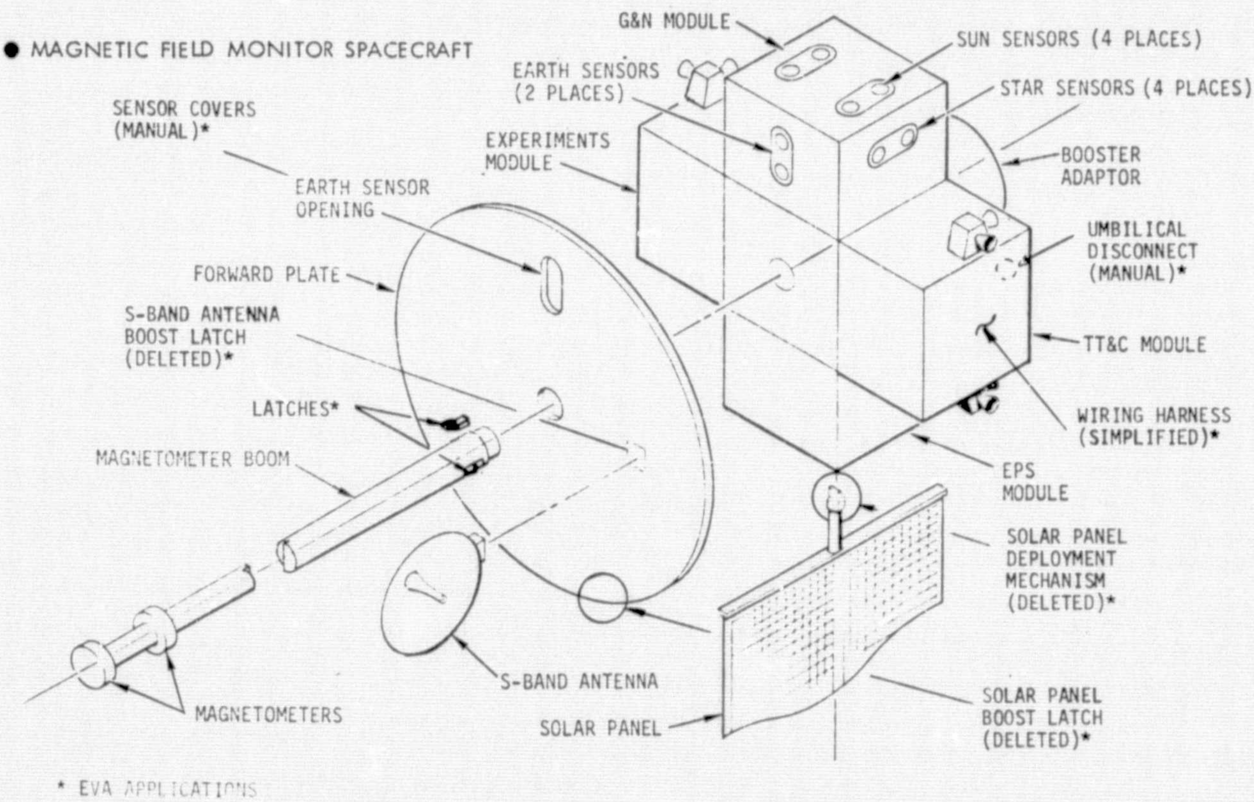


Figure 4-6. EVA Applications Analysis

as well as the experiment sensors, will most likely be protected during the boost phase, and up to spacecraft separation from the orbiter. In this specific example, at least five automated sensor covers could be replaced by manual covers. These could be among the last EVA tasks performed on the spacecraft to reduce the potential for contamination. (Short-term exposure for other than cryo-cooled sensors is not considered a problem.) Other EVA tasks eliminate

the mechanized solar deployment and latch, antenna latch, remote umbilical, and simplify the spacecraft wiring. An additional EVA task, specifically applicable to the MAGSAT, was to install the magnetometer boom on orbit, thus increasing the overall available cargo bay volume which is penetrated by the 4.4-m fixed boom of the baseline configuration.

WBS Organization

The payload configuration definitions were organized around the conventional work breakdown structure format described earlier. Subsystems and components were identified down to the level required to differentiate between the baseline and EVA designs. For example, when the EVA application substituted a manually operated cover on a sun sensor for the solar panel, the WBS definition was carried down to that detail level and the estimated cost differences recorded at the same level. This procedure was followed as required for all the representative payloads in order to provide the required inputs to the CAM IV costing program. Figure 4-7 depicts this task for a representative payload using a solar array assembly.

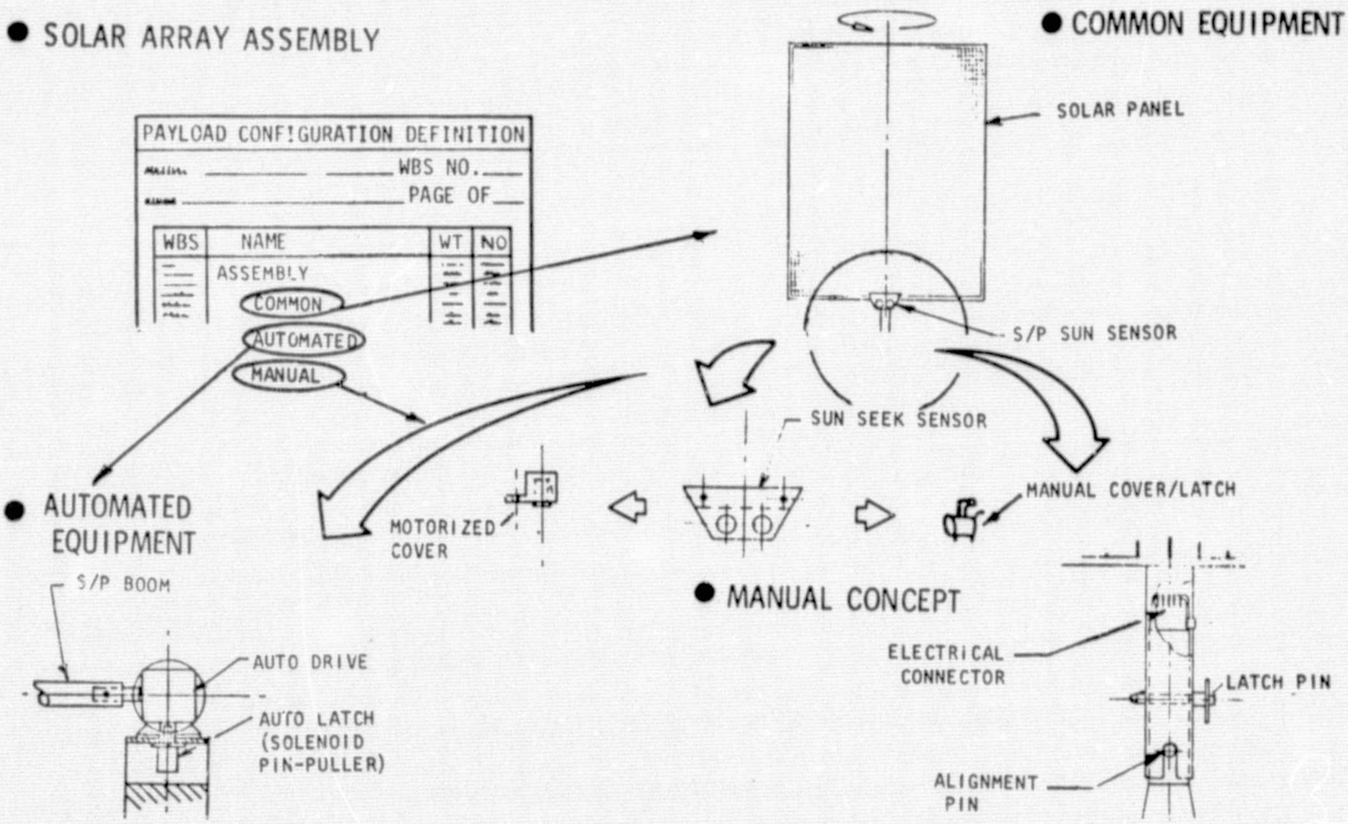


Figure 4-7. Representative Payload Costing Example

This figure identifies three groups of equipment: common, automated, and manual. The examples are: common assemblies of the solar array; the automated motor deployment subsystem, which is required only for the baseline mode; and an EVA concept replacing the motorized deployment subsystem. In addition, a group of subsystems and components were required to be added to the common

group to provide complete hardware for the EVA-oriented designs. Included in this group were modifications to the payload support equipment and special items such as EVA workstations which are necessary to perform EVA operations on the payload. Adding costs for the basic group and this group's items provides the payload costs for the EVA-oriented designs. In general, weight and performance data were available for equivalent elements from vendor quotes. These data were weight scaled and costed from the appropriate CER. Since manual designs generally did not exist, weight and material composition were determined for study designs which are contained in the engineering drawings.

Based on the WBS designed for this study a tabular, indentured breakdown was prepared on the flight hardware for each of the representative payloads as a basis for evaluating the design and to establish required EVA provisions and alternates to the baseline design. This breakdown also was used to cost the flight hardware from the appropriate CER.

Table 4-3 presents the indentured breakdown for each representative payload flight hardware. The baseline system data were taken from available sources. Where sufficient details were lacking, engineering estimates of that equipment were made. The weight was compared to the CER generated for that system and the dollars-per-kilogram value noted. The EVA alternatives to the baseline designs were assigned separate WBS numbers permitting cost calculations and summing in the programmed costing model.

Weights Analysis

Weights data were important for costing in that the CER's were weight scaled as described previously. Excellent source data were available at system, subsystem and (for conventional design) at component levels. Detailed weight estimates were sometimes necessary for retrievable capability of automated devices and for manual alternatives for the following: (1) latches and tiedowns; (2) folding, retraction and actuation; and (3) electrical umblicals. Antenna or solar array erection mechanisms which have the usual spring actuation and locking device were, in some cases, modified first to provide for retrievability and also to manually position the device and use manually operated locks. Other manual-operated levers could replace more elaborate electrically actuated systems, such as in the case of radar array antenna extension.

Electrical umbilicals for the deployed and retrievable payloads presented a unique problem since no such devices, to our knowledge, have been employed on a space vehicle. Some design proposal work has been done on automated electrical receptacles for missiles, but no known design has evolved for the type of application likely to be encountered on the Shuttle payloads. Such devices would require complex automation. High engagement/disengagement forces require special consideration for EVA. Both designs would be complex, but preliminary weight estimates lean toward the manual operation as slightly lighter weight. Both concepts assume a caging arrangement to align and engage the pins of the plug and receptacle. The weight estimate was based on a Bendix design concept for a missile blind receptacle.

Table 4-3. Representative Payload Flight Hardware WBS SHEET 1

REPRESENTATIVE PAYLOAD NAME EARTH OBSERVATORY SATELLITE (EOS) WBS NO. 11.00.00.00.00

SIZE (m) SC 11.7(L) 2.8(D) FSS 3.9 3.2 SOURCE DATA SSPD, 7/74, SD DESIGN STUDIES, PHASE B STUDY DOCUMENTATION Page 1 of 3

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.0.0.0	FLIGHT SYSTEM	BASELINE EVA	3996.5/ 3967.1	
02.1.0.0	STRUCTURES AND MECHANISMS (INCLUDES ENVIRONMENTAL CONTROL)	BASELINE EVA	725/ 724.7	
02.1.1.0	TRANSITION RING		180	
02.1.2.0	INSTRUMENT SECTION	BASELINE EVA	160/ 159.7	
-1	BASIC STRUCTURE AND THERMAL		148.7	6
-12	POSITION INDICATORS		0.5	12
-13	POSITION LOCKS		10.8	6
-33	POSITION LOCKS		6	6
-34	EVA WORKAIDS (2-FT RESTR LOCATIONS, 1 SET HANDHOLDS/LATCHES)		5	-
02.1.3.0	SUBSYSTEMS SECTIONS		350	5
02.1.4.0	DOCKING PROBES		35	4
02.3.0.0	GUIDANCE, NAVIGATION AND STABILIZATION	BASELINE EVA	272/ 267.5	
02.3.1.0	INERTIAL ELEMENTS		221.9	
02.3.2.0	STAR TRACKER SUN SENSOR ASSEMBLY	BASELINE EVA	10.1/ 5.6	
-11	OPTICS COVER & MECHANISM - AUTO		5.1	3
-31	OPTICS COVER & MECHANISM - MANUAL		0.6	3
-2	STAR TRACKER AND CONTROL CIRCUITS		5.0	
02.3.3.0	COMPUTER ELECTRONICS & INTEGRATION		40	1
02.4.0.0	AUXILIARY ATTITUDE CONTROL SYSTEM	PROPELLANT = 67 KG	105	
02.5.0.0	ELECTRICAL POWER SYSTEM	BASELINE EVA	530/ 514.3	1
02.5.1.0	SOLAR ARRAY ASSEMBLY		256/ 240.4	1
-1	SOLAR PANELS AND STRUCTURE	176 M^2	213.6	1
-2	ORIENTATION ASSEMBLY		13.4	1
-13	SUN SENSOR COVERS - AUTO		3.4	2
-33	SUN SENSOR COVERS - MANUAL		0.4	2
-14	SOLAR PANEL DEPLOYMENT - AUTO		10	1
-34	SOLAR PANEL DEPLOYMENT - EVA		3	1

Table 4-3.

SHEET 2

REPRESENTATIVE PAYLOAD NAME EARTH OBSERVATORY SATELLITE (EOS) WBS NO. 11.00.00.00.00

SIZE (m) SEE PAGE 1 of 3 SOURCE DATA SEE PAGE 1 of 3 Page 2 of 3

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
-15	SOLAR PANEL DEPLOYMENT BOOST RESTRAINT - AUTO		3.6	1
-35	SOLAR PANEL DEPLOYMENT BOOST RESTRAINT - MANUAL		2	2
-16	CONTROL WIRING & ELECTRONICS - AUTO		12	
-36	CONTROL WIRING & ELECTRONICS - MANUAL		8	
02.5.2.0	POWER CONTROL DISTRIBUTION AND BATTERIES		274	
-1	WIRE HARNESS		58	
-2	CONTROL ELECTRONICS		100	
-3	BATTERY GROUP		116	
02.6.0.0	COMMUNICATION AND DATA	BASELINE/EVA	345/343	
02.6.1.0	TT&C		236	
02.6.2.0	WIDEBAND COMMUNICATIONS		67	
02.6.3.0	ANTENNA ASSEMBLY - AUTO		42	
02.6.33.0	ANTENNA ASSEMBLY - MANUAL		40	
02.7.0.0	KICK STAGE, PROPULSION MODULE		941	
02.8.0.0	ASSEMBLY AND CHECKOUT		-	
02.9.0.0	MISSION EQUIPMENT	BASELINE EVA	1078.5/ 1071.5	
02.9.1.0	THEMATIC MAPPER	BASELINE/EVA	272/270.2	
-1	INSTRUMENT ASSEMBLY		162	
-12	COVER ASSEMBLY - AUTO		2	1
-32	COVER ASSEMBLY - MANUAL		0.2	1
-3	MODULE STRUCTURE		108	
02.9.2.0	HIGH-RESOLUTION IMAGER	BASELINE/EVA	273/271.2	
-1	INSTRUMENT ASSEMBLY		163	1
-12	COVER ASSEMBLY - AUTO		2	1
-32	COVER ASSEMBLY - MANUAL		0.2	1
-3	MODULE STRUCTURE		108	1
02.9.3.0	DATA COLLECTION SYSTEM		34.1	
02.9.4.0	RADAR IMAGER SYSTEM	BASELINE/EVA	227/223.6	
-1	ELECTRONICS		90.8	
-2	ANTENNA		130.8	1
-13	BOOST LOCKS - AUTO		5.4	2
-33	BOOST LOCKS - EVA		2.0	2

Table 4-3.

SHEET 3

REPRESENTATIVE PAYLOAD NAME EARTH OBSERVATORY SATELLITE (EOS) WBS NO. 11.00.00.00

SIZE (m) SEE PAGE 1 of 3 SOURCE DATA SEE PAGE 1 of 3 Page 3 of 3

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.9.5.0	POLLUTION MONITORING PACKAGE		272.4	
03.2.0.0	ORBITAL SUPPORT UNIT	BASELINE EVA	2533/ 2522.9	
.03.2.1.0	PAYLOAD RETENTION & POSITIONING SYSTEM (PRPS)	BASELINE EVA	1152/ 1127.3	1
-1	RETENTION CRADLE STRUCTURE & SUBSYSTEMS		479.3	1
-12	RETENTION CRADLE SEGMENT LOCKS - AUTO		9.1	1 SET
-32	RETENTION CRADLE SEGMENT LOCKS - MANUAL		2.0	1 SET
-13	RETENTION CRADLE SEGMENT ROTATION UNITS - AUTO		13.6	2
-33	RETENTION CRADLE SEG. ROTATION UNITS - MANUAL		4.0	2
-14	POSITIONING PLATFORM STRUCTURE		636.0	1
-15	PP TO PL CAPTURE LATCHES - AUTO		7.2	4
-35	PP TO PL CAPTURE LATCHES - MANUAL		2.0	4
-16	PP ROTATION MECHANISM - AUTO		6.8	1
-36	PP ROTATION MECHANISM - MANUAL		4.0	1
.03.2.2.0	SPECIAL-PURPOSE MANIPULATOR SYSTEM (SPMS)		1290.0	1
-1	MODULE EXCHANGE MECHANISM		575.0	1
-2	MODULE MAGAZINE		715.0	1
.03.2.13.0	DATA MANAGEMENT - AUTO		75.0	1
.03.2.33.0	DATA MANAGEMENT - EVA		72.7	1
.03.2.4.0	ELECTRICAL POWER	BASELINE EVA	16.1/ 12.9	1
-1	JUNCTION BOXES		0.5	
-2	INTERFACE UNITS		2.0	
-13	WIRING & CONNECTORS, PRPS - AUTO		13.6	1 SET
-33	WIRING & CONNECTORS, PRPS - EVA		10.4	1 SET
.03.2.35.0	EVA WORK AIDS		20.0	-

SHEET 4

Table 4-3.

REPRESENTATIVE PAYLOAD NAME GRAVITY AND RELATIVITY SATELLITE (GRS) WBS NO. 12.00.00.00.00

SIZE (m) 6.3 (L) 2.2 (D) SOURCE DATA SSPD, JULY 1974 Page 1 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.0.0.0	FLIGHT SYSTEMS	BASELINE EVA	600/ 575.9	
02.1.0.0	STRUCTURES AND MECHANISMS	BASELINE/EVA	31.8/35.0	1
02.1.1.0	BASIC		31.8	
02.1.32.0	EVA ADDED WORK AIDS		3.2	16
02.2.0.0	ENVIRONMENTAL CONTROL		22.7	
02.3.0.0	GUIDANCE, NAVIGATION & CONTROL		22.5	1
02.4.0.0	ATTITUDE CONTROL SYSTEM		18.0	1
02.5.0.0	ELECTRICAL POWER AND DISTRIBUTION	SOLAR, BATTERY	100/ 79.1	1
02.5.1.0	SOLAR ARRAY ASSEMBLY	BASELINE EVA	78.5/ 58.9	4
.1	SOLAR PANELS		31.0	4
.12	LATCH ASSEMBLY - AUTO		2.7	4
.32	LATCH ASSEMBLY - MANUAL		1.8	4
.13	DEPLOYMENT MECHANISM - AUTO		22.8	4
.33	DEPLOYMENT MECHANISM - MANUAL		7.2	4
.14	SUN SENSOR COVERS - AUTO		4.0	4
.34	SUN SENSOR COVERS - MANUAL		0.9	4
02.5.1.5	SOLAR ORIENTATION MECHANISM		18	4
02.5.2.0	ELECTRICAL EQUIP & S/C DISTRIBUTION	BASELINE EVA	21.5/ 20.7	
.11	HARNESS - AUTO		6.0	1
.31	HARNESS - MANUAL MODE		5.2	1
.2	ELECTRICAL EQUIPMENT		15.5	
02.6.0.0	TT&C		25.0	1
02.7.0.0	IUS		1120	NO COSTS
02.8.0.0	ASSEMBLY & CHECKOUT		--	
02.9.0.0	MISSION EQUIPMENT	BASELINE/EVA	380/373.1	(5)
02.9.1.0	PRECESSION GYRO SET	H_e COOLED	292.8 FULL 157.8 DRY	2
02.9.2.0	STAR TELESCOPE (ACQUISITION)	BASELINE/EVA	5.6/4.8	1
.1			4.6	1
.12	COVER - AUTO		1.0	1
.32	COVER - MANUAL		0.2	1

SHEET 5

Table 4-3.

REPRESENTATIVE PAYLOAD NAME GRAVITY AND RELATIVITY SATELLITE (GRS) WBS NO. 12.00.00.00.00

SIZE (m) SEE PAGE 1 of 2 SOURCE DATA SEE PAGE 1 of 2 Page 2 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.9.3.0	STAR TRACKER	BASELINE/ EVA	59.0/ 54.5	1
.1	TELESCOPE UNIT		54.0	1
02.9.3.12	SUN SHADE - AUTO	FIXED	4.0	1
.32	SUN SHADE - MANUAL	STOWABLE	0.3	1
.13	TELESCOPE COVER - AUTO		1.0	1
.33	TELESCOPE COVER - MANUAL		0.2	1
02.9.4.0	EARTH HORIZON SENSOR		22.6 21.0	1
.1	OPTICAL SYSTEM		20.6	2
.12	OPTICS COVER - AUTO		2.0	2
.32	OPTICS COVER - MANUAL		0.4	2
03.0.0.0	SUPPORT		--	
03.1.0.0	GROUND SUPPORT EQUIPMENT		--	
03.2.0.0	ORBITAL SUPPORT UNIT	BASELINE/ EVA	713.3/ 714.7	
03.2.1.0	SPACELAB PALLET		590	NO COSTS
03.2.2.0	PAYLOAD PROVISIONS	BASELINE/ EVA	123.3/ 124.4	
.11	PAYLOAD RETENTION LATCHES - AUTO		4.0	3
.31	PAYLOAD RETENTION LATCHES - MANUAL		3.2	3
.12	POWER/SIGNAL UMBILICAL - AUTO		6.8	
.32	POWER/SIGNAL UMBILICAL - MANUAL		3.6	
.13	CRYO VENT LINE - AUTO		5.5	
.33	CRYO VENT LINE - MANUAL		3.6	
.14	WIRE HARNESS & CONTROLS - AUTO		30.0	
.34	WIRE HARNESS & CONTROLS - MANUAL		26.0	
.5	STANDARD RETENTION FRAME		77.0	
.36	EVA-ADDED WORK AIDS		11.3	

SHEET 6

Table 4-3.

REPRESENTATIVE PAYLOAD NAME LARGE SPACE TELESCOPE (LST) WBS NO. 13.00.00.00.00

SIZE (m) 12.4(L) 3.9(D) SOURCE DATA (A) SSPD, JULY 1974 (B) LST PHASE A FINAL REPORT, VOL. II, DEC. 1972 Page 1 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
.02.0.0.0	FLIGHT SYSTEM	BASELINE/ EVA	9573.4/ 9500.6	
.02.1.0.0	STRUCTURES AND MECHANISMS	BASELINE/ EVA	3185.0/ 3165.0	
.02.1.1.0	BASIC + OTA		2840	
.02.1.1.12	SUNSHADE MECHANISM - AUTOMATED		345	
.02.1.1.32	SUNSHADE MECHANISM - MANUAL		320	
.02.1.1.33	EVA HANDHOLDS, ETC	SPACECRAFT INSTALL.	5	
.02.2.0.0	ENVIRONMENTAL CONTROL	PASSIVE	120	
.02.3.0.0	GUIDANCE, NAVIGATION & STABILIZATION	BASELINE/ EVA	520.4/ 516.6	
.02.3.1.0	BASIC G&N		495.5	1
.02.3.2.0	FIXED STAR TRACKER SYSTEM	BASELINE/EVA	21.2/17.6	2
.1	OPTICS		16.4	2
.12	STAR TRACKER COVERS - AUTOMATED		4.8	2
.32	STAR TRACKER COVERS - MANUAL		1.2	2
.02.3.3.0	SUN SENSOR	BASELINE/EVA	3.7/2.2	1
.1	OPTICS		2.0	1
.12	COVER - AUTOMATED		1.7	1
.32	COVER - MANUAL		0.2	1
.02.4.0.0	ATTITUDE CONTROL	34.6 KG, PROPELLANT	118.6	
.02.5.0.0	ELECTRICAL POWER & DISTRIBUTION	SOLAR ARRAYS & BATTERIES BASELINE/EVA	648.2/ 609.8	1
.02.5.1.0	SOLAR ARRAY ASSEMBLY	BASELINE/ EVA	302.8/ 277.1	
.1	SOLAR ARRAYS	33.5 M^2	184.7	
.12	BOOST LATCHES - AUTOMATED		1.7	2
.32	BOOST LATCHES - MANUAL		1.0	2
.3	ORIENTATION & OPTICS		10.0	
.14	SUN SENSOR COVER - AUTOMATED		3.4	2
.34	SUN SENSOR COVER - MANUAL		0.4	2
.15	SOLAR ARRAY DEPLOYMENT - AUTOMATED		103	2
.35	SOLAR ARRAY DEPLOYMENT - MANUAL		81	2
.02.5.2.0	BATTERY & CONDITIONING EQUIPMENT		216.7	
.02.5.13.0	CONTROL/WIRING - AUTOMATED		128.1	
.02.5.33.0	CONTROL/WIRING - MANUAL		116.0	

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Table 4-3.

REPRESENTATIVE PAYLOAD NAME LARGE SPACE TELESCOPE (LST) WBS NO. 13.00.00.00.00

SIZE (m) SEE PAGE 1 of 2 SOURCE DATA SEE PAGE 1 of 2 Page 2 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
.02.6.0.0	TT&C	BASELINE/EVA	82.6/77.0	1
.02.6.1.0	BASIC TT&C ELECTRONICS & ANTENNA		69.0	
.02.6.12.0	COMM. ANTENNA EXTENSION - AUTOMATED	"ASTROMAST" 2 15-FT BOOMS	10.0	2
.02.6.32.0	COMM. ANTENNA EXTENSION - MANUAL		6.0	2
.02.6.13.0	COMM. ANTENNA LATCH - AUTOMATED		3.6	2
.02.6.33.0	COMM. ANTENNA LATCH - MANUAL		2.0	2
.02.7.0.0	KICKSTAGE	NONE	-	-
.02.8.0.0	ASSEMBLY & CHECKOUT		-	
.02.9.0.0	MISSION EQUIPMENT		4898.6	
.02.9.1.0	OPTICAL TELESCOPE ASSEMBLY (OTA)	WITHOUT STRUCTURE	2690	
.02.9.2.0	SCIENTIFIC INSTRUMENTS		2208.6	
.1	FIELD CAMERAS		683	4
.2	ECHELLE SPECTROGRAPHS		275.2	4
.3	FAINT OBJECT SPECTROGRAPHS		551.6	2
.4	SUPPORT OPTICS, ETC.		698.8	
.03.0.0.0	SUPPORT EQUIPMENT			
.03.1.0.0	GSE		-	
.03.2.0.0	ORBITAL SUPPORT UNIT	DELIVERY ONLY BASELINE/EVA	334.8/ 337.6	
.03.2.1.0	SHUTTLE-PROVIDED RETENTION		(223.0)	-
.03.2.2.0	PAYLOAD PROVISIONS	BASELINE/EVA	111.8/ 1114.6	
.11	PSS, AUTO CONTROLS		75	
.31	PSS, MANUAL + AUTO CONTROLS		70	
.12	REMOTE UMBILICAL - AUTOMATED		6.8	2
.32	UMBILICAL - MANUAL		3.6	2
.13	WIRE HARNESS - AUTOMATED		30	
.33	WIRE HARNESS - MANUAL		26	
.34	EVA WORK AIDS		15	
.03.2.3.0	PLANNED SERVICING EQUIPMENT	BASELINE/EVA	1851/503	
.11	POSITIONING PLATFORM		650	
.12	SPECIAL PURPOSE MANIPULATOR		575	
.13	SPARES MAGAZINE - AUTOMATED		626	
.33	SPARES MAGAZINE - MANUAL		503	

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Table 4-3.

REPRESENTATIVE PAYLOAD NAME MINILAGEOS (MIN) WBS NO. 14.00.00.00.00

SIZE (m) 0.5d SPHERES SOURCE DATA SSPD, JULY 1974 Page 1 of 1

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.9.0.0	MISSION EQUIPMENT	PASSIVE LASER REFLECTOR SPHERES	204.0	2
03.0.0.0	SUPPORT EQUIPMENT			
03.1.0.0	GROUND SUPPORT EQUIPMENT			
03.2.0.0	ORBITAL SUPPORT UNIT	BASELINE/ EVA	205.8/ 203.9	
03.2.1.0	PALLET SEGMENT		(118)	
03.2.2.0	PAYLOAD-PROVIDED SUPPORT	BASELINE/ EVA	87.8/ 85.9	
.1	CONTAMINATION SHIELD STRUCTURE & COVER		80.0	1
.12	AUTOMATED CONTAMINATION SHIELD OPERATING MECH		4.2	1
.32	MANUAL CONTAMINATION SHIELD OPERATING MECH		1.4	1
.13	AUTOMATED SATELLITE EJECTION MECHANISM		1.8	2
.33	MANUAL SATELLITE EJECTION MECHANISM		1.0	2
.14	AUTO POWER HARNESS AND CONTROL CIRCUIT		1.8	1
03.2.2.35	EVA WORK AIDS		3.5	

SHEET 9

Table 4-3.

REPRESENTATIVE PAYLOAD NAME MAGNETIC FIELD MONITOR (MFM) WBS NO. 15.00.00.00.00

SIZE (m) 8.5(L) 2.2(D) SOURCE DATA (A) SSPD, JULY 1974 (B) SD IN-HOUSE DESIGN CONCEPTS Page 1 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.0.0.0	FLIGHT SYSTEM	LOW-COST REUSABLE 1500KM, 28.5-DEG ORBIT BASELINE/EVA	266.8/ 253.2	1
02.1.0.0	STRUCTURES AND MECHANISMS	BASELINE/EVA	69.0/ 71.0	1
02.1.1.0	BASIC STRUCTURE & RADIATION SHIELDING		69.0	1
02.1.32.0	EVA-ADDED HAND-HOLDS, ETC.		2.0	1
02.2.0.0	ENVIRONMENTAL CONTROL	INSULATION, COATINGS & 10 W HEATERS	2.3	1
02.3.0.0	GUIDANCE, NAVIGATION & STABILIZATION	BASELINE/ EVA	23.7/ 17.7	1
02.3.1.0	BASIC G&N		9.7	1
02.3.2.0	OPTICAL SYSTEMS	SUN & STAR SENSORS, EARTH HORIZON SENSORS	7.2	4
.11	COVERS & MECHANISMS - AUTO		6.8	4
.31	COVERS & MECHANISMS - MANUAL		0.8	4
02.4.0.0	ATTITUDE CONTROL	NITROGEN GAS	28.6	1
02.4.1.0	BASIC ACS		10.0	1
02.4.2.0	ACS CONSUMABLES		18.6	1
02.5.0.0	ELECTRICAL POWER & DISTRIBUTION	SOLAR PANELS, BATTERIES BASELINE/EVA	106.4/ 97.0	1
02.5.1.0	POWER CONTROL & BATTERIES		52.5	
02.5.2.0	SOLAR ARRAY SYSTEM	BASELINE/ EVA	43.9/ 39.0	
.1	SOLAR PANEL, 1.57 M^2		38.0	1
.12	SOLAR ARRAY ERECTION SYSTEM - AUTO	ELECTROMECHANICAL 90-DEG ROTATION	4.1	1
.32	SOLAR ARRAY INSTALLATION SYSTEM - MANUAL	ARRAY STORED IN PL BAY, INSTALLED IN ORBIT	1.0	1
.13	SOLAR ARRAY BOOST LOCK - AUTO	ELECTROMECHANICAL	1.8	1
.33	SOLAR ARRAY BOOST LOCK - MANUAL	MANUAL STORAGE LATCH IN PL BAY	0.0	1
02.5.13.0	WIRE HARNESS SYSTEM - AUTO		10.0	1
02.5.33.0	WIRE HARNESS SYSTEM - MANUAL		5.5	1
02.6.0.0	TT&C	BASELINE/ EVA	16.3/ 15.5	1
02.6.1.0	S-BAND ANTENNA ASSY	GIMBALED BASELINE/EVA	10.3/ 9.5	

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Table 4-3.

REPRESENTATIVE PAYLOAD NAME MAGNETIC FIELD MONITOR (MFM) WBS NO. 15.00.00.00.00

SIZE (m) SEE PAGE 1 of 2 SOURCE DATA SEE PAGE 1 of 2 Page 2 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.6.1.1	ANTENNA		8.5	
.12	ANTENNA BOOST LOCK - AUTO		1.8	
.33	ANTENNA BOOST LOCK - MANUAL		1.0	
02.6.2.0	BASIC TT&C COMPONENTS	B-IIA	6.0	1
02.7.0.0	KICK STAGE - IUS	NOT COSTED	--	1
02.8.0.0	ASSEMBLY AND CHECKOUT			
02.9.0.0	MISSION EQUIPMENT	BASELINE/EVA	20.5/ 21.1	1
02.9.1.0	VECTOR MAGNETOMETER		9.1	1
02.9.2.0	SCALAR MAGNETOMETER		9.1	1
02.9.3.0	MAGNETOMETER BOOM	FIXED	2.3	
02.9.33.0	EVA LATCH INSTALLATION	DETACHMENT	0.6	
03.0.0.0	SUPPORT EQUIPMENT			
03.1.0.0	GROUND SUPPORT EQUIPMENT			
03.2.0.0	ORBITAL SUPPORT UNIT	BASELINE/EVA	694.5/ 699.5	
03.2.1.0	SPACELAB PALLET	2.89 METER	590	NO COST
03.2.2.0	PAYLOAD PROVISIONS	BASELINE/EVA	104.5/ 109.5	
.1	PAYLOAD RETENTION FRAME		77.0	1
.12	AUTO PL BOOST LOCKS		3.9	4
.32	MANUAL PL BOOST LOCKS		3.1	4
.13	POWER & SIGNAL UMBILICALS - AUTO		13.6	2
.33	POWER & SIGNAL UMBILICALS - MANUAL		6.4	2
.34	EVA-ADDED WORK AIDS		12.0	1
.35	PANEL & BOOM LATCHES		2.0	4
.16	PAYLOAD WIRING HARNESS - AUTO		10.0	1
.36	PAYLOAD WIRING HARNESS - MANUAL		8.0	1

Table 4-3.

REPRESENTATIVE PAYLOAD NAME HIGH ALTITUDE EXPLORER (HAE) WBS NO. 16.00.00.00.00

SIZE (m) SC 1.6(L) 2.8(D) SC/IUS 10.5(L) 2.8(D) SOURCE DATA SSPDA, JULY 1974 Page 1 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.0.0.0	FLIGHT SYSTEM, 1.22D X 1.83	BASELINE/ EVA	447.5/ 443.5	1
02.1.0.0	STRUCTURES AND MECHANISMS	BASELINE/ EVA	54.5/ 57.7	1
02.1.2.0	EVA WORK AIDS		3.2	
02.2.0.0	ENVIRONMENTAL CONTROL	PASSIVE SYSTEM	9.1	1
02.3.0.0	GUIDANCE, NAVIGATION & STABILIZATION	BASELINE/ EVA	41.0/ 39.5	1
02.3.1.0	G&N INERTIAL ELEMENTS		35.1	1
.1	STAR TRACKER		4.2	1
.12	AUTO STAR TRACKER CONTAM COVER & MECHANISM		1.7	1
.32	MANUAL STAR TRACKER CONTAM COVER & MECHANISM		0.2	1
02.4.0.0	ATTITUDE CONTROL		163.0	1
02.4.1.0	COLD GAS PROPELLANT		108.5	1
02.4.2.0	ATTITUDE CONTROL & COMPONENTS		54.5	1
02.5.0.0	ELECTRICAL POWER & DISTRIBUTION	SOLAR CELLS & BATTERIES	59.0	1
02.6.0.0	TELEMETRY, TRACKING, & COMMAND		32.0	1
02.7.0.0	IUS		--	NO COST
02.8.0.0	ASSEMBLY & CHECKOUT		--	--
02.9.0.0	MISSION EQUIPMENT	BASELINE/EVA	88.9/ 83.2	1
02.9.1.0	VLF RECEIVER/ANTENNA	BASELINE/ EVA	22.0/ 20.0	1
.1	EXPERIMENT EQUIPMENT		17.4	1
02.9.2.0	ELECTRIC FIELD DETECTOR		13.6	2
02.9.3.0	MAGNETOMETER ASSEMBLY		24.4/ 22.2	2
.1	MAGNETOMETERS		17.2	2
02.9.4.0	SPECTROMETERS		20.4	2
02.9.5.0	LANGMUIR PROBE ASSEMBLY	BASELINE/ EVA	8.5/ 7.0	1
.1	PROBE		6.8	1
.12	PROBE COVER - AUTO		1.7	1
.32	PROBE COVER - MANUAL		0.2	1
02.9.1.12	VLF ANTENNA, AUTO DEPLOY		4.6	2
02.9.1.32	VLF ANTENNA, MANUAL DEPLOY		2.6	2

Table 4-3.

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REPRESENTATIVE PAYLOAD NAME HIGH ALTITUDE EXPLORER (HAE) WBS NO. 16.00.00.00.00

SIZE (m) SEE PAGE 1 of 2 SOURCE DATA SEE PAGE 1 of 2 Page 2 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.9.3.12	MAGNET. BOOM - AUTO		7.2	2
.32	MAGNET. BOOM - MANUAL		5.0	2
03.0.0.0	SUPPORT EQUIPMENT		--	
03.1.0.0	GSE		--	
03.2.0.0	ORBITAL SUPPORT UNIT	BASELINE/EVA	702.8/ 710.0	
03.2.1.0	SPACELAB PALLET	2.89 METER	590.0	1
03.2.2.0	PAYLOAD PROVISIONS	BASELINE/EVA	112.8/ 120.0	
.1	PAYLOAD RETENTION FRAME		77.0	1
.12	PAYLOAD BOOST LOCKS - AUTO		4.0	3
.32	PAYLOAD BOOST LOCKS - MANUAL		3.2	3
.13	POWER & DATA UMBILICAL - AUTO		6.8	1
.33	POWER & DATA UMBILICAL - MANUAL		3.6	1
.14	PAYLOAD WIRE HARNESS - AUTO		25.0	1
.34	PAYLOAD WIRE HARNESS - MANUAL		24.2	1
.35	EVA-ADDED WORK AIDS		12.0	1

Table 4-3.

SHEET 13

REPRESENTATIVE PAYLOAD NAME U.S. DOMSAT "C" (DOM) WBS NO. 17.00.00.00.00

SIZE (m) SC 4.2(L) 2.4(D) SC/IUS 12.5(L) 4.4(D) SOURCE DATA (A) SSPD, OCTOBER 1973 (B) SD TDRS CONCEPTS Page 1 of 1

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.0.0.0	FLIGHT SYSTEM	DOM COMM SATELLITES, TUG DELIVERY OF 3 UNITS TO GEOSYNCH ORBIT BASELINE/EVA	309.7/ 299.1	
02.1.0.0	STRUCTURES & MECHANISMS	BASELINE/EVA	41.3/ 46.3	1
02.1.1.0	BASIC		41.3	1
02.1.31.0	EVA WORK AIDS		5.0	1
02.2.0.0	ENVIRONMENT CONTROL		10.8	1
02.3.0.0	GUIDANCE, NAVIGATION & STABILIZATION	3-AXIS STABILIZED BASELINE/EVA	26.3/ 23.3	1
02.3.1.0	BASIC G&N COMPONENTS		22.9	1
02.3.12.0	AUTO HORIZON SCANNER SHIELDS		3.4	2
02.3.32.0	MANUAL HORIZON SCANNER SHIELDS		0.4	2
02.4.0.0	ATTITUDE CONTROL	16 THRUSTERS	36.9	1
02.4.1.0	ATTITUDE CONTROL & TANKS		14.5	
02.4.2.0	PROPELLANT		22.4	
02.5.0.0	ELECTRICAL POWER & DISTRIBUTION	BASELINE/EVA	69.9/ 68.3	1
02.5.1.0	BASIC EPS		66.3	1
02.5.13.0	SOLAR PANEL LATCH - AUTO		3.6	2
02.5.33.0	SOLAR PANEL LATCH - MANUAL		2.0	2
02.9.0.0	MISSION EQUIPMENT	BASELINE/EVA	124.5/ 113.5	1
02.9.1.0	COMMUNICATION EQUIPMENT		95.4	1
02.9.12.0	CABLE SETS - AUTO		10.5	3
02.9.31.0	CABLE SETS - MANUAL		9.5	3
02.9.18.0	ANTENNA LATCHES - AUTO		12.6	7
02.9.38.0	ANTENNA LATCHES - MANUAL		5.6	7
02.9.19.0	PL MODULE LATCH - AUTO (1.0)		6.0	6
02.9.39.0	PL MODULE LATCH - MANUAL (0.5)		3.0	6
03.3.1.0	STAGE ADAPTER		200	
03.3.32.0	EVA WORK AIDS		8.0	

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Table 4-3.

REPRESENTATIVE PAYLOAD NAME GEOPAUSE (GEO) WBS NO. 18.00.00.00.00

SIZE (m) SC 2.6(L) 2.0 (D) SC/IUS 10.7(L) 2.0(D) SOURCE DATA SSPD - JULY 1974 Page 1 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.0.0.0	FLIGHT SYSTEM	GEO SATELLITE, IUS DELIVERED TO 30,000 KM, 90-DEG ORBIT BASELINE/EVA	789.0/ 779.6	1
02.1.0.0	STRUCTURES & MECHANISMS	BASELINE/EVA	200.0/ 201.3	1
02.1.31.0	EVA HANDHOLDS, ETC.		1.3	
02.2.0.0	ENVIRONMENTAL CONTROL	PASSIVE PLUS HEAT PIPES AND HEATERS	20.0	1
02.3.0.0	GUIDANCE, NAVIGATION & STABILIZATION	3-AXIS BASELINE/EVA	80.0/ 74.4	1
02.3.1.0	SUN SENSOR SYSTEMS	BASELINE/EVA	10.2 7.4	2
.1	SUN SENSOR OPTICS		6.8	2
.12	SUN SENSOR COVERS & MECHANISMS - AUTO		3.4	2
.32	SUN SENSOR COVERS & MECHANISMS - MANUAL		0.6	2
02.3.2.0	HORIZON SENSOR SYSTEMS	BASELINE/EVA	11.6 8.8	2
.1	HORIZON SENSOR SYSTEMS OPTICS		8.2	
.12	HORIZON SENSOR COVERS & MECH - AUTO		3.4	2
.32	HORIZON SENSOR COVERS & MECH - MANUAL		0.6	2
02.3.3.0	G&N INTERNAL COMPONENTS SET		58.2	1
02.4.0.0	ATTITUDE CONTROL SYSTEM (115.6 KG, PROP.)	NITROGEN GAS & JETS	180.0	1
02.5.0.0	ELECTRICAL POWER & DISTRIBUTION	SOLAR CELLS & BATTERIES BASELINE/EVA	120.0/ 119.4	1
02.5.10	INSTALLED ELECTRICAL ARRAYS		108.0	1
02.5.12.0	POWER HARNESS - AUTO		12.0	
02.5.32.0	POWER HARNESS - MANUAL		11.4	
02.6.0.0	TT&C		50.0	1
02.7.0.0	KICK MOTOR/IUS		--	
02.8.0.0	ASSEMBLY & CHECKOUT		--	
02.9.0.0	MISSION EQUIPMENT	BASELINE/EVA	139.0/ 134.5	1
02.9.1.0	RETROREFLECTOR ARRAY		13.0	2
.11	ARRAY COVERS - AUTO		5.1	
.31	ARRAY COVERS - MANUAL		0.6	
02.9.2.0	PRECISION TRANSMITTER/RCVR/TRANSPONDER		90.6	1
02.9.3.0	VERY LONG BASELINE INTERFEROMETER		30.3	1

Space Division
Rockwell International

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Table 4-3.

REPRESENTATIVE PAYLOAD NAME GEOPAUSE (GEO) WBS NO. 18.00.00.00.00

SIZE (m) SEE PAGE 1 of 2 SOURCE DATA SEE PAGE 1 of 2 Page 2 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
03.2.0.0	ORBITAL SUPPORT UNIT	BASELINE/EVA	705.8/ 704.0	1
03.2.2.11	PAYLOAD BOOST LOCKS & MECHANISMS - AUTO		4.0	3
.31	PAYLOAD BOOST LOCKS & MECHANISMS - MANUAL		3.2	3
.12	WIRE HARNESS & UMBILICAL - AUTO		26.8	2
.32	WIRE HARNESS & UMBILICAL - MANUAL		19.6	2
.33	EVA-ADDED WORK AIDS		7.0	1
.14	PSS - AUTO		8.0	
.34	PSS - MANUAL		7.2	
03.2.3.0	RETENTION FRAME		77.0	

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Table 4-3.

REPRESENTATIVE PAYLOAD NAME MARINER JUPITER ORBITER (MJO) WBS NO. 19.00.00.00.00

SIZE (m) SC 5.4(L) 3.96(D) SC/IUS 18.8(L) 3.96(D) SOURCE DATA SSPD - 1974 Page 1 of 1

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
.02.0.0.0	FLIGHT SYSTEM	BASELINE/EVA	2491/ 2489	1
.02.1.0.0	STRUCTURE AND MECHANISMS	BASELINE/EVA	182/185	1
.02.1.1.0	BASIC		182	2
.02.1.32.0	EVA ADDED WORK AIDS	FOR RTG COOLING COVER REMOVAL	3	
.02.2.0.0	ENVIRONMENTAL CONTROL	PASSIVE	23	1
.02.3.0.0	GUIDANCE, NAVIGATION, STABILIZATION & PROPULSION	3-AXIS, 300 LB THRUST ENGINE	910	1.6
.02.4.0.0	ATTITUDE CONTROL (26 KG PROPELLANT)	MASS EXPULSION	105	1.3
.02.5.0.0	ELECTRICAL POWER AND DISTRIBUTION	RTG POWER BASELINE/EVA	225/220	1
.02.5.1.0	BASIC ELECTRICAL POWER		165	1.7
.02.5.2.0	CABLING AND PYROTECHNICS		60	1
.02.5.32.0	CABLING ONLY, MANUAL		55	0.7
.02.6.0.0	TT&C		72	1
.02.7.0.0	KICK MOTOR	SC PROPULSION, MMH/N2O4	890	1
.02.7.1.0	BASIC PROPULSION SYSTEM		160	
.02.7.2.0	PROPELLANT		730	
.02.9.0.0	MISSION EQUIPMENT		84	1
.03.0.0	OSU SERVICING EQUIPMENT	BASELINE/EVA	350/348	
.03.2.2.1	PROTECTIVE COVER		300	1
.12	COVER LATCH SYSTEM - AUTOMATED		24	1
.32	COVER LATCH SYSTEM - MANUAL		12	0.2
.13	COVER ROTATION SYSTEM - AUTOMATED		4	1.2
.33	COVER ROTATION SYSTEM - MANUAL		2	0.2
.14	RTG COOLING MECHANISM - AUTOMATED	RMS AIDED, INCLUDES JACKET WEIGHT	20	1
.34	RTG COOLING MECHANISM - MANUAL	INCLUDES JACKET WEIGHT	16	0.9
.15	OSU POWER/CONTROL CABLE - AUTOMATED		2	1
.35	EVA-ADDED PROVISIONS		18	1

Table 4-3.

REPRESENTATIVE PAYLOAD NAME SHUTTLE INFRARED TELESCOPE FACILITY (SIRTF) WBS NO. 21.00.00.00.00

SIZE (m) 3 PALLET SECTIONS SOURCE DATA SIRTF ROCKWELL PROPOSAL, INITIAL STUDY DATA& SSPD 7/74 Page 1 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.0.0.0	Flight System			
02.09.0.0	Telescope Assembly 1.5 M Cryo Cooled 2d X 6	Baseline/EVA	3997/3824	-
02.09.01.0	Cylinder Housing	Baseline/EVA	1617/1611	-
.11	Thermal Isolators	Automated	9	6
.31	Thermal Isolators	Manual	6	6
.12	Sun Shade	Automated	9	1
.32	Sun Shade	Manual	6	1
.3	Structures		1599	-
03.02.02.01	EVA Work Aids		7	-
02.09.02.0	Front Cover Assembly Boost Protection and Calibration	Baseline/EVA	144/118	-
.11	Front Cover Latch Mechanism	Automated	25	6
.31	Front Cover Latch Mechanism	Manual	11	6
.12	Cover Swing Arm	Automated	34	1
.32	Cover Swing Arm	Manual	22	1
.03	Cover Structure		85	-
02.09.03.0	Rear Cover Assembly	Baseline/EVA	64/54	-
.11	Electrical Connector Assembly	Automated	11	1
.31	Electrical Connector Assembly	Manual	7	1
.12	Cryogenic Fill/Vent Connector	Automated	18	1
.32	Cryogenic Fill/Vent Connector	Manual	12	1
.03	Cover Structure		35	-
02.09.04.0	Cryogenic System		395	-
.01	Cryogenic Fluid	1.7 M^3	220	-
.02	Plumbing		175	-
02.09.05.0	Optical System		680	-
02.09.06.0	Electronics	Telescope Control	115	-
02.09.07.0	Sensor System	7 Instruments and Control Elements	155	-
02.09.08.0	Gimbal Mount System	Baseline/EVA	709/643	
.11	Three-Axis Mount, IPS Clamps	Automated	70	6
.31	Three-Axis Mount, IPS Clamps	Manual	20	6
.12	Electronics and Harness	Automated	21	1

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Table 4-3.

REPRESENTATIVE PAYLOAD NAME SHUTTLE INFRARED TELESCOPE FACILITY (SIRTF) WBS NO. 21.00.00.00.00

SIZE (m) 3 PALLET SECTIONS SOURCE DATA SIRTF ROCKWELL PROPOSAL, INITIAL Page 2 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.09.08.32	Electronics and Harnesses	Manual	18	1
.13	Drive System	Baseline	98	1
.33	Drive System	Manual	85	1
.04	Instrument Pointing Mount		520	1
02.09.09.0	Water Storage System	Baseline/EVA	118/46	-
.11	Water Storage Tanks	Automated	100	-
.12	Plumbing, Monitoring	Automated	18	-
.31	Water Bags	Manual	28	-
.32	Ejection Device	Manual	18	-

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Table 4-3.

REPRESENTATIVE PAYLOAD NAME ATMOSPHERIC AND SPACE PLASMA PHYSICS (AMPS) WBS NO. 22.00.00.00.00

SIZE (m) SHORT MODULE + 3 PALLET SECTIONS SOURCE DATA SSPDA 7/74 Page 1 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.0.0.0	Flight System	Baseline/EVA	9723/9607	-
02.09.0.0	Remote Sensing Platform Assy	Baseline/EVA	946/935	-
.01.0	Mechanical Units		590	-
.02.0	Sunshade	Baseline/EVA	123/112	1
.01	Structure		100	-
.11	Motor Drive	Automated	23	1
.31	Drive Unit	Manual	12	1
.0	Sensor System	24.5 M^3	233	1
.0	Lidar System, AP 200	Baseline/EVA	253/251	-
02.10.01.0	Transmitter/Receiver and Barrel	0.5d X 2.0 M	104	1
02.10.02.0	Lidar Mount	Baseline/EVA	149/147	1
.01	Drive Mechanism and Structure		145	-
.12	Contamination Cover	Automated	4	1
.32	Contamination Cover	Manual	2	1
02.11.0.0	Gimbaled Accelerator System, AP 300	Baseline/EVA	710/708	-
.01.0	Ion Accelerator Assembly		150	1
.02.0	Electron Accelerator Assembly		15	1
.03.0	Storage Bank Assembly		200	1
.04.0	MPD-Arc Assembly		300	1
.05.0	Gimbal Mount System	Baseline/EVA	45/43	-
.01	Swivel Base and Mechanism		39	1
.12	Boost Latches	Automated	6	4
.32	Boost Latches	Manual	4	4
02.12.0.0	Transmitter Coupler System, AP 400	Baseline/EVA	190/186	-
.01.0	Transmitter/Coupler		170	3
.02.0	330 M Dipole Element	Baseline/EVA	20/16	-
.01	Antenna		13	-
.12	Dipole Extension/Retraction Unit	Automated	7	-
.32	Rod Couplings	Manual	3	-

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Table 4-3.

REPRESENTATIVE PAYLOAD NAME ATMOSPHERIC AND SPACE PLASMA PHYSICS (AMPS) WBS NO. 22.00.00.00.00

SIZE (m) SHORT MODULE + 3 PALLET SECTIONS SOURCE DATA SSPDA 7/74 Page 2 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.13.0.0	Boom System	Baseline/EVA	642/637	-
.01.0	Astromast Assembly		560	2
.02.0	Experiment Platform		14	-
.03.0	Five-Meter Unit	Baseline/EVA	8/3	-
.03.11	Astromast Assembly	Automated	8	2
.03.31	Pole-Mast Assembly	Manual	3	2
.04.0	33-Meter Dipole Antenna		10	1
.05.0	Sensor Group		50	-
02.14.0.0	Deployable Units System, AP 600	Baseline/EVA	923/912	-
.01.0	Barium Canisters		24	5
.02.0	Shaped Charge Containers		810	5
.03.0	Ballon Units	Spherical Insulated/ Conducting	11	2
02.14.04.0	Deployable Unit	Baseline/EVA	70/61	-
.01	Mount		58	1
.12	Mechanism	Automated	12	5
.32	Mechanism	Manual	3	2
02.14.05.0	Balloon Deployment Devices	Baseline/EVA	8/6	-
.11	Mechanism	Automated	8	-
.31	Mechanism	Manual	6	-
02.15.0.0	Subsatellite System, AP 700	Baseline/EVA	678/676	
.01.0	Subsatellite	VLF/Instrument Units	648	2
.12.0	Ejection Mechanism/Latches	Automated	30	2
.32.0	Ejection Mechanism/Latches	Manual	28	2
02.16.0.0	Control and Display Assembly	Baseline/EVA	5381/5281	1
.01.0	Control and Display Equipment	Common	5281	-
.12.0	Control and Display Equipment	Baseline	100	-
02.17.0.0	Support Equipment		25	
.01.0	EVA Workaids		25	-

Table 4-3.

REPRESENTATIVE PAYLOAD NAME ADVANCED TECHNOLOGY LABORATORY NO. 5 (ATL) WBS NO. 23.00.00.00.00

SIZE (m) FULL PALLET SOURCE DATA SSPDA LEVEL B 7/74, IN-HOUSE STUDY Page 1 of 4

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.0.0.0	Flight Hardware	Baseline/EVA	4479/4190	-
02.09.0.0	Microwave Interferometer and Autonomous Navigation	Baseline/EVA	540/512	-
01.0	RF and Electronics		85	-
02.0	Structures and Mechanisms	Baseline/EVA	455/427	-
.11	38-Meter Boom Assembly, ST 003	Automated	364	4
.31	38-Meter Boom Assembly, ST 003	Manual	336	4
.02	Boom Mount, ST 004		91	1
02.10.0.0	Autonomous Navigation, XST 004	Baseline/EVA	250/231	-
01.0	Sensor Assembly	Baseline/EVA	160/149	1
.01	Star Field and Landmark Tracker		23	1
.13	Inertial Platform Gimbal and Lock	Automated	135	1
.33	Inertial Platform Gimbal and Lock	Manual	124	1
.02	TV Camera ST 025		2	1
02.10.02.0	Gimbal Platform Assembly	Baseline/EVA	90/82	1
.01	Platform Pedestal Mount		30	-
.02	Gimbaling Mechanism		50	-
.13	Boost Latches	Automated	10	-
.33	Boost Latches	Manual	2	-
02.11.0.0	Microwave Radiometer	Baseline/EVA	626/609	-
.01.0	Antenna Assembly	Baseline/EVA	380/377	-
.01	Inflatable Antenna		136	-
.12	Erection Structure	Automated	115	-
.32	Pole Assemblies	Manual	106	-
.13	Pressurization System	Automated	23	
.33	Pressurization System	Manual	20	
.02.0	RF/Electronics		41	-
02.11.03.0	Radiometer Mounting Base	Baseline/EVA	205/191	-
.01	Mounting Base Ring		75	-
.12	Deployment and Drive Mechanism	Automated	20	-
.32	Deployment and Drive Mechanism	Manual	12	-
.03	Gimbal System		100	-
.14	Gimbal Latches	Automated	10	-

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Table 4-3.

REPRESENTATIVE PAYLOAD NAME ADVANCED TECHNOLOGY LABORATORY NO. 5 (ATL) WBS NO. 23.00.00.00.00

SIZE (m) FULL PALLET SOURCE DATA SSPDA LEVEL B 7/74, IN-HOUSE STUDY Page 2 of 4

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
.34	Gimbal Latches	Manual	4	-
02.12.0.0	Search and Rescue and Imaging Radar	Baseline/EVA	986/961	-
01.0	Antenna Assembly	Baseline/EVA	589/564	-
.01	Antenna	Slotted Waveguide	459	1
.12	Antenna Mount and Erection Mechanism	Automated	135	1
.32	Antenna Mount and Pivot Assembly	Manual	110	1
.02.0	RF/Electronics		397	-
02.13.0.0	Lidar Measurement, Cirrus Clouds and Lower Stratosphere Aerosals	Baseline/EVA	401/391	-
01.0	Instrumentation		314	-
.01	Transmitter and Data Unit		232	-
.02	Receiver Telescope		68	-
.03	Cine Camera		9	-
02.0	Mechanisms and Support Equipment	Baseline/EVA	87/77	-
.11	Sensor Canister and Cover	Automated	25	1
.31	Sensor Canister and Cover	Manual	19	1
.12	Pressurization System	Automated	12	1
.32	Pressurization System	Manual	10	1
.13	Gimbal Mount and Latches	Automated	50	-
.33	Gimbal Mount and Latches	Manual	40	-
02.14.0.0	Barium Plasma Cloud Release	Baseline/EVA	348/334	-
02.14.01.0	Optical Instrumentation		195	-
.01/04	Cameras and Photometer		193	-
.05	Pointing Telescope		2	-
02.0	Mechanisms	Baseline/EVA	153/139	-
.11	Container and Cover Mechanism	Automated	86	1
.31	Container and Cover Mechanism	Manual	78	1
.02	Gimbal System		45	1
.13	Gimbal Latches	Automated	10	1
.33	Gimbal Latches	Manual	6	1
.14	Pressurization System	Automated	12	1
.34	Pressurization System	Manual	10	1

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Table 4-3.

REPRESENTATIVE PAYLOAD NAME ADVANCED TECHNOLOGY LABORATORY NO. 5 (ATL) WBS NO. 23.00.00.00.00

SIZE (m) FULL PALLET SOURCE DATA SSPDA LEVEL B 7/74, IN-HOUSE STUDY Page 3 of 4

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.15.0.0	Mapping of Upper Atmosphere Neutral Gas Parameters	Baseline/EVA	260/241	-
01.0	Probe Assembly		120	1
.01	Molecular Beam Subdivider		80	1
.02	Mass Spectrometer, Mol Beam		35	5
.03	Support Electronics		5	1
02.15.02.0	Structures and Meachnisms	Baseline/EVA	140/121	-
.11	Boom Assembly	Automated	55	-
.31	Boom Assembly	Manual	45	-
.12	Canister and Cover Mechanism	Automated	85	-
.32	Canister and Cover Mechanism	Manual	76	-
02.16.0.0	Ultraviolet Meteor. Spectroscopy	Baseline/EVA	116/106	-
.01.0	Instrument Assembly		55	-
.01	Spectrographs/Photomultiplier		28	4
.02.0	Structures and Mechanisms	Baseline/EVA	62/52	-
.11	Container and Cover Mechanism	Automated	50	-
.31	Container and Cover Mechanism	Manual	42	-
.12	Pressurization System	Automated	12	-
.32	Pressurization System	Manual	10	-
02.17.0.0	Environmental Effects on Non-Metallic Materials	Baseline/EVA	34/24	-
02.17.01.0	Experiment Assembly	Baseline/EVA	4/1	-
.01	Sun Sensor		0.2	-
.12	Specimen Container and Covers	Automated	4	-
.32	Specimen Container and Covers	Manual	1	-
02.0	Structures and Mechanisms	Baseline/EVA	30/23	-
.11	Extendible Boom	Automated	20	1
.31	Extendible Boom	Manual	16	1
.12	Container and Cover Mechanism	Automated	4	1
.32	Container and Cover Mechanism	Manual	3	1
.13	Pressurization System	Automated	6	1
.33	Pressurization System	Manual	4	1

Table 4-3.

REPRESENTATIVE PAYLOAD NAME ADVANCED TECHNOLOGY LABORATORY NO. 5 (ATL) WBS NO. 23.00.00.00.00

SIZE (m) FULL PALLET SOURCE DATA SSPDA LEVEL B 7/74, IN-HOUSE STUDY Page 4 of 4

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.18.0.0	External Contamination Measurement XST 040	Baseline/EVA	73/72	–
01.0	Sensor System		41	9
02.1	Structures and Mechanisms	Baseline/LVA	32/31	–
02.18.02.01	Optical Effects Module		11	1
.02	Tray		16	1
.13	Cover and Mechanism	Automated	5	1
.33	Cover and Mechanism	Manual	4	1
02.19.0.0	Controls, Displays and Data	Baseline/EVA	560/470	–
.11.0	Controls, Displays and Data	Automated	160	–
.31.0	Controls, Displays and Data	Manual	70	–
.02.0	Controls, Displays and Data	Basic	400	–
02.20.0.0	EVA Workaids		25	–

Table 4-3.

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REPRESENTATIVE PAYLOAD NAME PHYSICS AND CHEMISTRY FACILITY NO. 1 (PCF) WBS NO. 24.00.00.00.00

SIZE (m) LARGE MODULE SOURCE DATA SSPDA 7/74 Page 1 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.0.0.0	Flight System	Baseline/EVA	815/587	-
02.09.0.0	Chemistry Experiments In Space	Baseline/EVA	154/152	-
.01.0	Sensor System		59	-
.01	Gas Canister		5	4
.02	EUV, VIS, IR Spectro-photometers		35	3
.03	Electron Probe		5	2
.04	Mass Spectrometer		7	1
.05	Electrometer		2	1
.06	Temperature Probe		1	1
.07	Telemetry Package		4	1
02.09.02.0	Boom System	Baseline/EVA	95/93	-
.01	Airlock Boom, Support and Can		84	2
.12	Extend/Retract Mechanism	Automated	2	2
.03	Sensor/Phenomena Gen. Platforms		9	2
02.10.0.0	Neutral Species Mass and Energy Analysis	Baseline/EVA	109/98	-
.01.0	Deployment System	Baseline/EVA	59/48	-
.01	Airlock Boom and Container		22	1
.12	Boom Extension Mechanism	Automated	2	1
.32	Boom Extension Mechanism	Manual	1	1
.13	Sensor Boom Container	Automated	14	1
.33	Sensor Boom Container	Manual	6	1
.04	Sensor Boom Fixture		18	1
.15	Sensor Boom Extension	Automated	3	1
.35	Sensor Boom Extension	Manual	1	1
02.0	Sensor System		50	-
.01	Mass and Energy Analyzer		18	1
.02	Power Supply		14	1
.03	Electron Beam Generator		18	1
02.11.0.0	Flame Chemistry		103	-
.01.0	Sensor System		40	5
.02.0	Chamber/Tank System		63	1

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Table 4-3.

REPRESENTATIVE PAYLOAD NAME PHYSICS AND CHEMISTRY FACILITY NO. 1 (PCF) WBS NO. 24.00.00.00.00

SIZE (m) LARGE MODULE SOURCE DATA SSPOA 7/74 Page 2 of 2

WBS	NAME	TYPE/DESCRIPTOR	TOTAL WEIGHT (kg)	No. UNITS
02.12.0.0	Ion Beam Experiment	Baseline/EVA	245/78	-
.01.0	Sensor System		38	3
.02.0	Mechanisms and Structures	Baseline/EVA	207/41	-
.11	Scientific Airlock	Automated	150	1
.12	Airlock Platform Extender	Automated	15	1
.13	Sensor Boom and Container	EVA	36	1
.33	Sensor Boom and Container	Manual	35	1
.04	Gas Storage Bottles		5	3
.15	Boom Deployment Mechanism	Automated	1	1
02.13.0.0	Support Electronics	Baseline/EVA	152/146	1
.11.0	Mini-Computer	Automated	50	1
.02.0	Oscilloscope		14	1
02.13.03.0	Digital Recorder		45	1
.04.0	Mass and Energy Electronics		18	1
.05.0	Controls and Displays		25/22	1
.11	Controls and Displays	Auto. Mode	25	1
.31	Controls and Displays	EVA	22	1
02.14.0.0	Photographic Devices		10	-
.01.0	Cine Camera		5	1
.02.0	TV Camera		5	1
02.15.0.0	Mechanical Devices	Baseline/EVA	45/11	-
11.0	Work Bench	Auto. Mode	45	-
32.0	EVA Workaids	Manual Mode	11	-

To facilitate the efficient movement of the EVA personnel, certain work platforms, hand-holds, steps and rails are necessary. The weight estimates of these devices were based on layouts of the particular payload involved.

The weight of the basic hand-held power tool was estimated, based upon an electric motor with a variable speed reduction feature incorporated. To cover the various types of operations with the power tool it was assumed accessories would be required with different types of heads. The weight estimates of these devices were based on a minimal requirement of different types of attachments. Weight summary data comparisons are presented on the previous table.

Weight estimates for special EVA provisions were also made to include the following: (1) work platforms, (2) hand-holds, steps and rails, (3) basic hand power tools, and (4) power tool attachments and accessories. These estimates were based on Apollo/Skylab data, and on in-house design concepts.

The weight estimates of the EVA alternatives to automated latches and tie-downs are based on the replacement of the electromechanical devices (motors, solenoids, gearing, etc.) or on the design and materials for manual leverage devices. A technical evaluation was made of each representative payload. This review resulted in technical characteristics and WBS item listings. Through technical comparisons, a relationship was established to an analogous payload for which both technical and cost data were available. In turn, a complexity relation, by subsystem or type of hardware, was rationalized through comparative analysis of the selected payload and the benchmark hardware typically described in Section II.

Complexity Factors

Having established the pertinent technical data, the evaluation was then broadened to extract the necessary cost information to project baseline cost. Complexity factors, developed by comparing the selected payload to one which was analogous, were applied to the result of the cost-per-kilogram calculation to convert to a total cost for each line item of the WBS.

The complexity factor is based on an analysis employed to determine the relative design, development, test and manufacturing relationship of a previously built or designed system to the new development. To assess complexity comparisons, subsystem design requirements were examined in relation to the mission requirements of the selected system. The mission requirements of the representative payloads were then compared with historical data to estimate the complexity factors for each item. Each of the selected payloads and their subsystems were reviewed in this manner and the results used in the final costing of the baseline payload.

The complexity factors were furnished to the Study Technical Monitor with complete costing data. Structures were generally 1:1 with the appropriate CER weight scale; however, EOS for example, was 1.4 on modular structural elements. Mechanical elements were at 1.0 to 1.2, with EVA alternatives generally at 0.2 to 0.25. Subsystems were almost always analogous based on technical evaluation, but with the GN&C for LST rated at 1.5, and MJO rating slightly higher than 1.0. Mission equipment and standard vendor elements (e.g., Astromast) were based

largely on NASA, vendor or other contractor published data. In many cases direct identification of instruments, optics, etc., was possible--in other cases, technical evaluation for analogy was made. Support in some instances was obtained from NASA payload centers.

Definitions of the baseline payload and deletions and additions resulting from EVA application were identified in the technical characteristics WBS listing. These were treated individually and appropriate cost relationships were applied, depending on the depth or level of the breakdown structure cited.

Once the analysis was completed, and the various factors to be used were determined, the actual computation of the cost and final output was generated by a computer program referred to as CAM IV.

4.1.4 CAM IV Costing Program

The computer costing system selected for this study permitted preparation of cost estimates to four levels of detail. The low level of cost detail enhances the degree of depth in the evaluation of cost impact penalties or cost-effectiveness savings associated with EVA concepts.

The CAM IV system was selected because it is easy to use and flexible, and has unique features advantageous to the EVA study. The model is capable of handling and compiling data at the level of motors, hand gear boxes, or work platforms which would be modified, replaced, or added by an EVA design. Functions or operations can also be handled because these are also defined and organized in the WBS tree format. The model did not restrict the study to any particular cost methodology or set of CER's because these are inputs to the model.

The capacity of the model is such that it can handle and print out data on any number of WBS elements in a WBS tree limited only by the core memory size of the computer, which permits it to handle many thousands of items, if desired, on a single run. The cost coding feature with a potential of handling 81 categories which cut across the WBS structure was uniquely applicable to the development and comparison of costs for the baseline and the EVA operational systems.

The EVA study used a coding capability of the CAM-IV model described below to compile the total baseline system and the total EVA system costs separately within a common work breakdown structure accounting system encompassing either alternative. Codes were used to flag all items which were deleted, replaced, or modified by an EVA operational system design. All new or modified elements for the EVA operational system were defined and flagged with a code number. On a single run, the computer summed and printed costs for the total baseline system and the total EVA system separately, including the common items in the work breakdown structure in both systems.

Code numbers from 1 to 9 could be placed in any of the three code columns of WBS Item Cards. When a particular code number or combination of code numbers is called for, the program selects the costs only from the WBS Item Cards with corresponding code numbers. These are then printed out separately. Up to 1000 possible code category printouts are possible. The code numbers used may be given any names desired and these will appear at the head of the printout.

A zero in any of the three code columns means ignore the corresponding code for that item on the WBS cards on the run being called for.

The availability of the summing codes selected allows the costs of alternate design concepts to be compared within a single program run. For example, where design or operational options exist at any level, the alternative concepts can be entered at the appropriate WBS level (levels 7 through 4) and summed to the program level (level 3) through use of the summing codes.

For example, design options may exist in the solar array deployment mechanism and other hardware elements, with resulting impact on systems engineering, reliability, test and integration, etc. The WBS and CAM IV cards can be set up to sum these costs to various totals by use of the code entries. Figure 4-8 illustrates a modified WBS, in which some WBS items remain unchanged (i.e., are common to both payload concepts) while other WBS items are unique to one concept or the other only (e.g., baseline and EVA concepts). If one code is retained to distinguish non-recurring and recurring costs, then the remaining two codes can be used as follows to distinguish Common, Baseline Concept and EVA Concept items. Note that because of CAM IV programming, new WBS numbers must also be entered in that no WBS item can carry more than one cost.

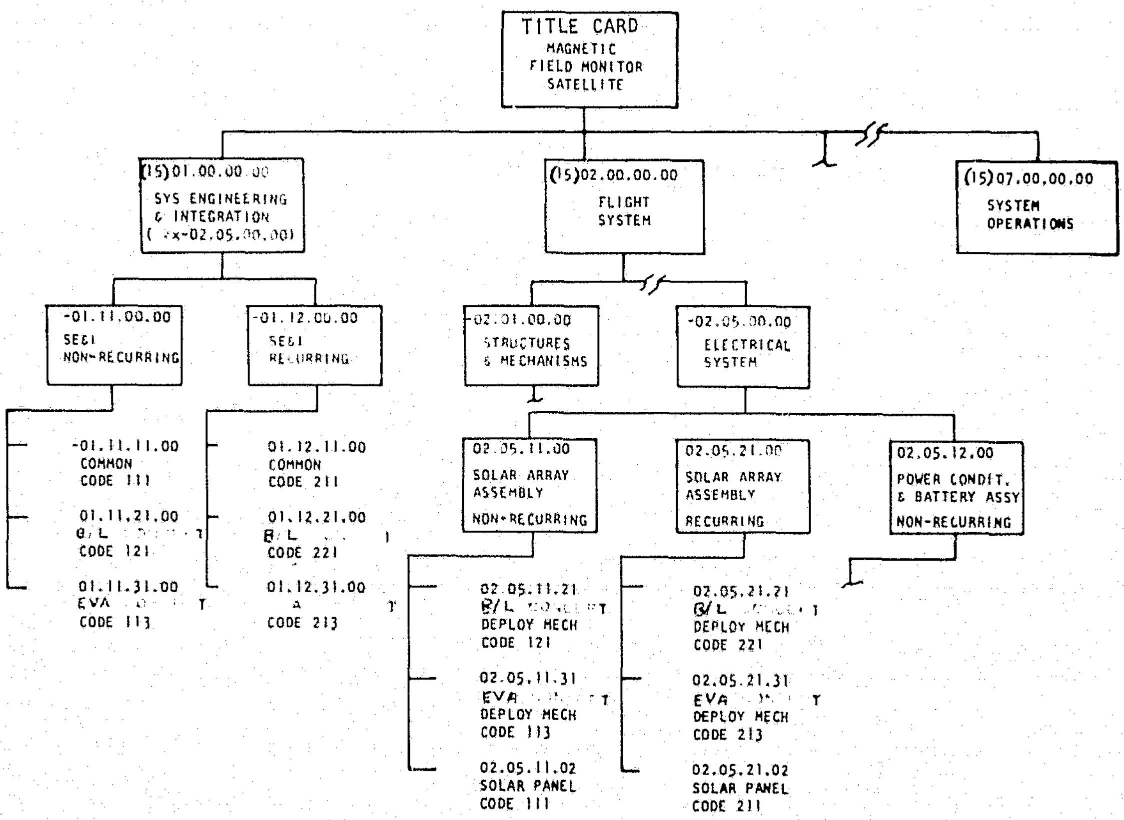

Figure 4-8. Example of the Use of Summing Codes for Alternate Concepts

Codes used in the study were as follows:

Code Columns

A	B	C	
X	1	1	WBS item common to both Concepts
X	2	1	WBS item unique to Baseline Concept only
X	1	3	WBS items unique to EVA Concept only

X coded as required for non-recurring (1), recurring (2), or Operations (3).

To sum the Baseline Payload in total, request code run 001. To sum the EVA-oriented payload in total, request code run 010. To compare only the unique costs of the alternate concepts, request code runs 020 and 003.

The Cost Analysis Model (CAM) IV computer program was applied to the indentured format of the WBS shown previously. Output data from the CAM IV program was summed to eight different totals for each representative payload as follows:

COSTS	BASELINE PAYLOAD	EVA-ORIENTED PAYLOAD
TOTAL PAYLOAD PROGRAM	X	X
NON-RECURRING (DDT&E)	X	X
RECURRING (FIRST UNIT)	X	X
REMOTE/AUTOMATED ELEMENTS (MODIFIED OR DELETED FOR EVA)	X	
EVA ELEMENTS (SUBSITUTED OR ADDED)		X

Costs were printed out at all levels and summed at all intermediate levels as well as the totals listed above. Data for cost areas are independently available such as program management, flight hardware, orbital support unit (OSU, etc.

Table 4-4 presents the summary costing for the representative payloads. The data show totals, non-recurring and first-unit recurring costs for baseline and EVA payloads, as well as gross and net savings. Additional details are shown later with the discussion on extrapolated costs.

4.2 PROGRAM MISSION MODEL AND COST SAVINGS EXTRAPOLATION

An extensive systems analysis was conducted in a logical process for attributing routine cost savings to a total Shuttle traffic and mission model. Each spacecraft and sortie payload defined in the SSPD was examined for technical comparison with the 13 representative payloads. Subsequently, SSPD payloads were correlated with accepted traffic model data. Finally, cost savings were ascribed to these payloads based on relative complexity, number of programs, units, and mission equipments as discussed later.

Table 4-4. Representative Payload Summary Costing

PAYLOAD	BASELINE CONCEPT COST			EVA CONCEPT COST			GROSS SAVINGS	EVA INCR	NET SAVINGS
	NR + REC	NR	REC	NR + REC	NR	REC			
EOS	233.0	170.5	62.5	230.7	168.7	62.0	5.4	3.1	2.3
GRS	45.8	33.7	12.1	43.9	32.1	11.8	3.0	1.1	1.9
LST	180.0	124.3	55.7	166.5	115.6	50.9	16.9	3.4	13.5
MIN	2.4	1.9	0.5	2.2	1.8	0.4	0.2	0.0	0.2
MFM	16.4	11.9	4.5	15.3	11.1	4.2	1.7	0.6	1.1
HAE	25.1	19.1	6.0	24.7	18.7	6.0	1.4	1.0	0.4
DOMSAT	23.9	17.0	6.9	23.0	16.3	6.7	1.4	0.5	0.9
GEOPAUSE	41.0	29.6	11.4	39.9	28.8	11.1	1.8	0.7	1.1
MJO	46.8	32.1	14.7	45.6	31.1	14.5	3.6	2.3	1.3
SIRTF	72.8	58.9	13.9	66.0	53.1	12.9	11.3	4.5	6.8
AMPS	245.5	109.2	136.3	238.5	103.7	134.8	11.1	4.1	7.0
ATL	149.7	111.0	38.7	135.5	99.5	36.0	21.0	6.8	14.2
PHYS-CHEM	35.4	27.7	7.7	27.7	21.5	6.2	10.1	2.4	7.7
TOTAL	1117.8	746.9	370.9	1059.5	702.0	367.5	88.9	30.5	58.4

4.2.1 Payload Correlation and Grouping

Since technical characteristics of many Shuttle payloads are only consistently defined in the SSPD Level A/B documents, the costing of all payloads by relative complexity to its representative payload was based on these data. However, the payloads were first grouped with each of the representative payloads. This task was accomplished differently for automated spacecraft and sortie payloads, as described below.

Automated Spacecraft

Since the nine representative automated spacecraft had been grouped by low cost or current design, reusable or expendable and low earth orbit, high-energy orbit or planetary escape, the SSPD spacecraft had to be so organized. However, only the orbital data appear in the SSPD; therefore the MSFC traffic model descriptors (LCE, CDE, etc.) had to be matched to the SSPD spacecraft. There are 81 spacecraft designated in the SSPD. Seven of these have no MSFC designation and were therefore omitted from the study model on the logic that if they did not appear in the January 1974 Traffic Model they would be less likely to be viable payloads in a reduced (572) flight schedule. Five other payloads were eliminated by examination of the traffic model, when non-Shuttle flights were specified. The final selection will be discussed later. Table 4-5 lists the correlation data for automated spacecraft. Generally, the SSPD identified a correlating NASA Headquarters payload number. However, additional correlation was required in that traffic model payload designators expand on the Payload Model numbers occasionally, and do not always reflect SSPD definition. The table shows several examples which were selected where correlation was based on other factors such as description or scheduling of the payloads. For example SSPD numbers AS-02 and AS-03, and virtually all of the HE and AP groups were assigned by evaluation. The group assigment by representative payload is apparent from the desciptor and orbit data.

Sortie Payloads

Correlation and grouping of sortie payloads offered a different problem in that (1) no MSFC descriptors were furnished, (2) the SSPD used for selecting the representative payloads did not refer to MSFC Traffic Model designators, and (3) only one Payload Model designator is assigned per discipline compared to numerous SSPD payload designators. Consequently, sortie payloads were grouped according to technical characteristics. A total of 93 sortie payloads are listed in the SSPD with only 11 payload designators in the NASA Payload Model. The MSFC Traffic Model does carry lettered *sub-designators*; however, no coorelation could be definitely established with the SSPD. Twenty-five SSPD payloads were eliminated initially on the basis of weight (less than ~1000 kg) as reflecting essentially carry-on or piggyback experiments. Eight additional payloads were deleted as being all module. Other payloads were omitted when examination showed that they were essentially variations of the same experiment hardware. Table 4-6 shows the payloads from the SSPD in total and as selected for Sortie groups 1, 2, 3, or 4, as described in Section II of this report.

Table 4-5. Automated Spacecraft Identification

PAYLOAD NUMBER			SSPD NAME	MSFC DESCRIPTION	ORBIT	
HQ NASA	MSFC	SSPD			LEO	HEO
AST-6	AST-6	AS-01	LARGE SPACE TELESCOPE	CDR	X	
AST-1	AST-1A	AS-02	EXTRA CORONAL LYMAN ALPHA EXLPORER	CDR		X
AST-1	AST-1A	AS-03	COSMIC BACKGROUND EXPLORER	CDR	X	
AST-1	AST-1B	AS-05	ADVANCED RADIO EXPLORER	CDR		X
--	--	AS-07	3m AMBIENT TEMPERATURE IR TELESCOPE	--	--	--
--	--	AS-11	1.5m IR TELESCOPE	--	--	--
--	--	AS-13	UV SURVEY TELESCOPE	--	--	--
--	--	AS-14	1.0m UV-OPTICAL TELESCOPE	--	--	--
AST-8	AST-8	AS-16	LARGE RADIO OBSERVATORY ARRAY (LROA)	CDR		X
--	--	AS-17	30m IR INTERFEROMETER	--	--	--
AST-9	AST-9B	HE-01	LARGE X-RAY TELESCOPE FACILITY	CDR	X	
AST-5	AST-5	HE-03	EXTENDED X-RAY SURVEY	CDR	X	
AST-5	AST-5	HE-05	HIGH LATITUDE COSMIC RAY SURVEY	CDR	X	
PHY-1	PHY-1A	HE-07	SMALL HIGH ENERGY SATELLITE	CDR	X	
AST-5	AST-5	HE-08	LARGE HIGH ENERGY OBS A (Gamma Ray)	CDR	X	
AST-4	AST-4	HE-09	LARGE HIGH ENERGY OBS B (Magnetic Spectrom.)	CDR	NON-SHUTTLE	
AST-5	AST-5	HE-10	LARGE HIGH ENERGY OBS C (Nuclear Calorimeter)	CDR	X	
AST-9	AST-9A	HE-11	LARGE HIGH ENERGY OBS D (1.2x X-Ray Teles.)	CDR	X	
PHY-5	PHY-5	HE-12	COSMIC RAY LABORATORY	CDR	X	
AST-7	AST-7	SO-02	LARGE SOLAR OBSERVATORY	CDR	X	
AST-3	AST-3	SO-03	SOLAR MAXIMUM MISSION	CDR	X	
PHY-1	PHY-1A	AP-01	UPPER ATMOSPHERE EXPLORER	CDR		X
PHY-1	PHY-1B	AP-02	MEDIUM ALTITUDE EXPLORER	CDR		X
PHY-1	PHY-1C	AP-03	HIGH ALTITUDE EXPLORER	LCE		X
PHY-2	PHY-2A	AP-04	GRAVITY AND RELATIVITY SATELLITE - LEO	LCE	X	
PHY-3	PHY-3A	AP-05	ENVIRONMENTAL PERTURBATION SATELLITE - A	CDR		X
PHY-2	PHY-2B	AP-06	GRAVITY AND RELATIVITY SATELLITE - SOLAR	LCE		X
PHY-3	PHY-3B	AP-07	ENVIRONMENTAL PERBURTATION SATELLITE - B	CDR		X
PHY-4	PHY-4	AP-08	HELIOCENTRIC & INTERSTELLAR SPACECRAFT	CDE		X
EO-7	EO-7	EO-07	ADV. SYNCHRONOUS METEOROLOGICAL SAT.	LCE		X
EO-3	EO-3A,B,C	EO-08	EARTH OBSERVATORY SATELLITE	LCR	X	
EO-4	EO-4A,4B	EO-09	SYNCHRONOUS EARTH OBSERVATORY SATELLITE	CDR		X
EO-5	EO-5A/E	EO-10	APPLICATIONS EXPLORER (Special Purpose Sat.)	LCE	X[1]	X[2]
EO-6	EO-6	EO-12	TIROS 'O'	CDR		X
NN/D-8	NN/D-8	EO-56	ENVIRONMENTAL MONITORING SATELLITE	LCR		X
NN/D-9	NN/D-9	EO-57	FOREIGN SYNCHRONOUS METEOROLOGICAL SAT	CDR		X
NN/D-10	NN/D-10	EO-58	GEOSYN OPERATIONAL METEOROLOGICAL SAT.	CDR		X
NN/D-12	NN/D-12	EO-59	GEOSYN EARTH RESOURCES SATELLITE	CDR		X
NN/D-11	NN/D-11	EO-61	EARTH RESOURCES SURVEY OPERATIONAL SAT.	LCR	X	
NN/D-13	NN/D-13	EO-62	FOREIGN SYNCHRONOUS EARTH OBS SATELLITE	CDR		X
EOP-4	EOP-4	OP-01	GEOPAUSE	CDE		X
EOP-5	EOP-5	OP-02	GRAVITY GRADIOMETER	LCE	NON-SHUTTLE	
EOP-6	EOP-6A,B,C	OP-03	MINI-LAGEOS	CDE	X	
EOP-7	--	OP-04	GRAVSAT	CDE	NON-SHUTTLE	
EOP-8	EOP-8	OP-05	VECTOR MAGNETOMETER SATELLITE	LCR	X	
EOP-9	EOP-9	OP-06	MAGNETIC FIELD MONITOR SATELLITE	LCR		X
EOP-3	EOP-3	OP-07	SEASAT - B	LCE	NON-SHUTTLE	
NN/D-14	NN/D-14	OP-51	GLOBAL EARTH & OCEAN MONITOR SYSTEM	LCR	X	
--	--	SP-01	SPACE PROCESSING FREE-FLYER	--	X	
LS-1	LS-1	LS-02	BIOMEDICAL EXPERIMENT SCIENTIFIC SAT.	LCR	X	
ST-1	ST-1	ST-01	LONG DURATION EXPOSURE FACILITY	CDR	X	
PL-7	PL-7	PL-01	MARS SURFACE SAMPLE RETURN	LCE		X
PL-8	PL-8	PL-02	MARS SATELLITE SAMPLE RETURN	LCE		X
PL-10	PL-10	PL-03	PIONEER VENUS MULTIPROBE	LCE		X
PL-11	PL-11	PL-07	VENUS ORBITAL IMAGING RADAR	LCE		X
PL-12	PL-12	PL-08	VENUS BUOYANCY PROBE	LCE		X
PL-13	PL-13	PL-09	MERCURY ORBITER	LCE		X
PL-14	PL-14	PL-10	VENUS LARGE LANDER	LCE		X
PL-18	PL-18	PL-11	PIONEER SATURN/URANUS FLYBY	CDE		X
PL-19	PL-19	PL-12	MARINER JUPITER ORBITER	LCE		X

1 - MSFC No. EO-5C,5D
2 - MSFC No. EO-5A,B,E

Table 4-5. Automated Spacecraft Identification (continued)

PAYLOAD NUMBER			SSPD NAME	MSFC DESCRIPTION	ORBIT	
HQ NASA	MSFC	SSPD			LEO	HEO
PL-20	PL-20	PL-13	PIONEER JUPITER PROBE	CDE		X
PL-21	PL-21	PL-14	SATURN ORBITER	LCE		--
PL-22	PL-22	PL-15	URANUS PROBE/NEPTUNE FLYBY	CDE		X
PL-23	PL-23	PL-16	GANYMEDE ORBITER/LANDER	LCE		X
PL-26	PL-26	PL-18	ENCKE RENDEZVOUS	LCE	NON-SHUTTLE	
PL-27	PL-27	PL-19	HALLEY COMET FLYBY	LCE		X
PL-28	PL-28	PL-20	ASTEROID RENDEZVOUS	LCE		X
PL-17	PL-17	PL-22	PIONEER SATURN PROBE	CDE	NON-SHUTTLE	
NN/D-1	NN/D-1	CN-51	INTELSAT	CDR		X
NN/D-2	NN/D-2A	CN-52	U.S. DOMSAT 'A'	LCE		X
NN/D-2	NN/D-2B	CN-53	U.S. DOMSAT 'B'	CDR		X
NN/D-3	NN/D-3	CN-54	DISASTER WARNING SATELLITE	LCR		X
NN/D-4	NN/D-4	CN-55	TRAFFIC MANAGEMENT SATELLITE	LCE		X
NN/D-5	NN/D-5	CN-56	FOREIGN COMMUNICATIONS SATELLITE A	CDR		X
NN/D-2	NN/D-2C	CN-58	U.S. DOMSAT 'C'	CDR		X
NN/D-6	NN/D-6	CN-59	COMMUNICATIONS R&D /PROTOTYPE SATELLITE	LCE		X
NN/D-5	NN/D-5	CN-60	FOREIGN COMMUNICATIONS SATELLITE B	CDR		X
LUN-2	LUN-2	LU-01	LUNAR ORBITER	LCE		X
LUN-3	LUN-3	LU-02	LUNAR ROVER	CDE		X
LUN-4	LUN-4	LU-03	LUNAR HALO SATELLITE	LCE		X
LUN-5	LUN-5	LU-04	LUNAR SAMPLE RETURN	CDE		X

Table 4-6. Sortie Payloads

Payload Number			SSPD Name	Low Weight	Group Assigned
Traffic/ Payload Model No.	Config (Pallet/ Module)	SSPD No.			
AST-10	P	AS-01-S	1.5m Cryogenically-Cooled IR Telescope	-	1
		AS-03-S	Deep Sky UV Survey Telescope	-	1
		AS-04-S	1m Diffraction Limited UV Optical Telescope	-	1
		AS-05-S	Very Wide Field Galactic Camera	X	-
		AS-06-S	Calibration of Astronomical Fluxes	-	1
		AS-07-S	Cometary Simulation	-	1
		AS-08-S	Multipurpose 0.5m Telescope	X	-
		AS-09-S	30m IR Interferometer	-	2
		AS-10-S	Adv XUV Telescope	-	1
		AS-11-S	Polarimetric Experiments	-	1
		AS-12-S	Meteoroid Simulation	-	1
		AS-13-S	Solar Variation Photometer	X	-
		AS-14-S	1.0m Uncooled IR Telescope	-	1
		AS-15-S	3.0m Ambient Temperature IR Telescope	-	1
		AS-18-S	1.5m IR Interferometer	-	2
		AS-19-S	Selected Area Deep Sky Survey Telescope	-	1
		AS-20-S	2.5m Cryogenically-Cooled IR Telescope	-	1
		AS-31-S	Combined AS-01, -03, -04, -05S	-	1
		AS-41-S	Schwartzschild Camera	X	-
		AS-42-S	Far UV Electronographic Schmidt Camera/Spectrograph	X	-
		AS-43-S	UCB Black Brant Payload	X	-
		AS-44-S	XUV Concentrator/Detector	X	-
		AS-45-S	Proportional Counter Array	X	-
		AS-46-S	Wisconsin UV Photometry Experiment	X	-
		AS-47-S	Attached Far IR Spectrometer	X	-
		AS-48-S	Aries/Shuttle UV Telescope	X	-
		AS-49-S	First UCB Black Brant Payload	X	-
		AS-50-S	Combined UV/XUV Measurements (AS-04-S, 10-S)	-	1
		AS-51-S	Combined IR Payload (AS-01-S, 15-S)	-	1
		AS-54-S	Combined UV Payload (AS-03-S, 04-S)	-	1
		AS-61-S	Attached Far IR Photometer (Wide FOV)	X	-
		AS-62-S	Cosmic Background Anisotropy	X	-

Table 4-6. Sortie Payloads (continued)

Payload Number					
Traffic/ Payload Model No.	Config (Pallet/ Module)	SSPD No.	SSPD Name	Low Weight	Group Assigned
PHY-6		HE-11-S	X-ray Angular Structure	-	1
		HE-12-S	High Inclination Cosmic Ray Survey	-	-
		HE-13-S	X-ray/Gamma Ray Pallet	-	-
		HE-14-S	Gamma Ray Pallet	-	-
		HE-15-S	Magnetic Spectrometer	-	3
		HE-16-S	High Energy Gamma-Ray Survey	-	-
		HE-17-S	High Energy Cosmic Ray Study	-	-
		HE-18-S	Gamma Ray Photometric Studies	-	-
		HE-19-S	Low Energy X-ray Telescope	-	1
		HE-20-S	High Resolution X-ray Telescope	-	1
AST-11		SO-01-S	Dedicated Solar Sortie Mission (DSSM)	-	1
		SO-11-S	Solar Fine Pointing Payload	-	1
	P	SO-12-S	ATM Spacelab	-	1
PHY-7	M/P	AP-06-S	Atmospheric, Magnetospheric, and Plasmas in Space (AMPS)	-	2
EO-8	M	EO-01-S	Zero-G Cloud Physics Laboratory	X	-
	P	EO-05-S	Shuttle Imaging Microwave System (SIMS)	-	3
	P	EO-06-S	Scanning Spectroradiometer	X	-
	M/P	EO-07-S	Active Optical Scatterometer	X	-
EOP-10	M/P	OP-02-S	Multifrequency Radar Land Imagery	-	3
	M/P	OP-03-S	Multifrequency Dual Polarized Microwave Radiometry	-	3
	P	OP-04-S	Microwave Scatterometer	-	3
	M/P	OP-05-S	Multispectral Scanning Imagery	-	3
	M/P	OP-06-S	Combined Laser Experiment	-	3
SP-1	M/P	SP-01-S	SPA No. 1 - Biological (Manned) (B+C)	-	-
	M/P	SP-02-S	SPA No. 2 - Furnace (Manned) (F+C)	-	-
	M/P	SP-03-S	SPA No. 3 - Levitation (Manned) (L+C)	-	-
	M/P	SP-04-S	SPA No. 4 - General Purpose (Manned) (G+C)	-	-
	M/P	SP-05-S	SPA No. 5 - Dedicated (Manned) (B+F+L+G+C)	-	-
	P	SP-12-S	SPA No. 12 - Automated Furnace (FP+CP)	-	3
	P	SP-13-S	SPA No. 13 - Automated Levitation (LP+CP)	-	3
	M/P	SP-14-S	SPA No. 14 - Manned and Automated (B+G+C+FP+LP)	-	3
	P	SP-15-S	SPA No. 15 - Automated Furnace/Levitation (FP+LP+CP)	-	3
	M/P	SP-16-S	SPA No. 16 - Biological/General (Manned) (B+G+C)	-	3
	M/P	SP-19-S	SPA No. 19 - Biological and Automated (B+C+FP+LP)	-	3
	M	SP-21-S	SPA No. 21 - Minimum Biological (B+C)	-	-
	M	SP-22-S	SPA No. 22 - Minimum Furnace (Manned) (F+C)	-	-
	M	SP-23-S	SPA No. 23 - Minimum General (G+C)	-	-
	M	SP-24-S	SPA No. 24 - Minimum Levitation (Manned) (L+C)	-	-
LS-2	M/P	LS-04-S	Free Flying Teleoperator	-	2
	M	LS-09-S	Life Sciences Shuttle Laboratory	-	-
	C	LS-10-S	Life Sciences Carry-on Laboratories	X	-
ST-2	M/P	ST-04-S	Wall-less Chemistry + Molecular Beam (Facil No. 1)	-	4
	M	ST-05-S	Superfluid He + Particle/Drop Positioning (Facil No. 2)	X	-
	M	ST-06-S	Fluid Physics + Heat Transfer (Facil No. 3)	-	4
	M/P	ST-07-S	Neutral Beam Physics (Facil No. 4)	X	-
	P	ST-08-S	Integrated Real Time Contamination Monitor	X	-
	P	ST-09-S	Controlled Contamination Release	X	-
	M/P	ST-11-S	Laser Information/Data Transmission	X	-
	C	ST-12-S	Entry Technology	X	-
	P	ST-13-S	Wake Shield Investigation	X	-
	M/P	ST-21-S	ATL P/L No. 2 (Module + Pallet)	-	3
	M/F	ST-22-S	ATL P/L No. 3 (Module + Pallet)	-	3
	P	ST-23-S	ATL P/L No. 5 (Pallet Only)	-	3
CN-3	M/P	CN-04-S	Terrestrial Sources of Noise + Interference	-	3
	M/P	CN-05-S	Laser Communication Experimentation	X	-
	M/P	CN-06-S	Communication Relay Tests	-	3
	P	CN-07-S	Large Reflector Deployment	-	3
	M/P	CN-08-S	Open Traveling Wave Tube	-	3
	M/P	CN-11-S	Stars & Pads Experimentation	-	3
	M/P	CN-12-S	Interferometric Navigation & Surveillance Techniques	-	3
	M	CN-13-S	Shuttle Navigation Via Geosynchronous Satellite	X	-

C = Carry-On

4.2.2 Traffic Model Preparation

To properly extrapolate representative payload cost data to all other NASA payloads, several major factors were required to be established. Major cost elements defined for each representative payload, as discussed earlier, were as follows.

1. Program Non-Recurring (DDT&E)

   a. Flight hardware related (spacecraft and orbital support unit)
   b. Mission equipment (automated spacecraft or sortie payload)

2. Flight Unit Recurring (First Unit)

   a. Spacecraft
   b. Mission equipment
   c. Orbital support unit

In order to cost *represented* payloads, the appropriate *representative* payload DDT&E cost should be multiplied by the total number of programs. However, payload designators do not always correlate with programs. Cases exist where spacecraft or mission equipment are identified under more than one payload designator. For example, Foreign COMSAT automated spacecraft are designated in SSPD as CN56 and CN60. X-Ray Astronomy sorties are identified as HE-11, HE-19 and HE-20. Both cases were considered to constitute a single program. Similarly, one designator may represent one program, although it falls into more than one group, e.g., the Applications Explorer (SSPD EO-10) which was determined to divide 60-percent Tug-delivered LCE and 40-percent non-Tug LCE. Determination of number of programs in the model was based on evaluation and grouping or dividing "payloads" based on like characteristics and/or objectives.

The number of end item units and unique sets of mission equipment can only be derived from an examination of flight schedules. New items of orbital support units can be used many times.

In order to properly ascribe costs, all of the above factors need to be assessed. For example, only one program DDT&E was considered appropriate for the Earth Observatory program, with development of one common spacecraft. However, three unique sets of mission equipment have been defined for the EOS, and the traffic schedule indicates that four end items must be fabricated. Finally, the one orbital support unit could reasonably be expected to support the EOS flight schedule. Selection of programs was also based on commonality of discipline among payloads, and was especially influenced by the uniqueness or repeated use of a like spacecraft.

To determine final study flight schedules (and thus numbers of units and mission equipment), preliminary data which related the "572" flight schedule to the MSFC Traffic Model were used. The result is contained in total in Table 4-7, with all payloads grouped with their representative payload. Pertinent data from this table are summarized in Volume I, Executive Summary.

Table 4-7. Study Payload Model

NASA & NON-NASA/NON-DOD LOW EARTH ORBIT SPACECRAFT

GROUP	PAYLOAD MODEL NO.	TRAFFIC MODEL NO.	SSPD NO.	PROGRAMS QTY	PROGRAMS NAME	SPACECRAFT DDT&E	SPACECRAFT NAME/TYPE	SPACECRAFT UNITS	MISSION DDT&E
LCR	EO-3	EO-3A EO-3B EO-3C	EO-08 *	1	EARTH OBSERVATIONS	1	EARTH OBSERVATORY SATELLITE	3	1 1 1
	NN/D-11	NN/D-11	EO-61	1	EARTH RESOURCES SURVEY	1	ERS OPERAT. SATELLITE	2	3
	LS-1	LS-1	LS-02	1	BIOMEDICAL EXPERIMENT	1	BESS	5	4
	EOP-8	EOP-8	OP-05	1	EARTH VECTOR MAGNETIC FIELD MON.	1	VECTOR MAGNETOMETER SATELLITE	3	1
	NN/D-14	NN/D-14	OP-51	1	GLOBAL EARTH & OCEAN PHYSICS	1	GLOBAL EARTH & OCEAN MONITOR SYS.	6	3
NON-TUG LCR SUBTOTALS				5		5	EQUIV SHUTTLE FLIGHTS ______ 37.5	19	14
LCE	PHY-2	PHY-2A	AP-04 *	.5	GRAVITY & RELATIVITY	1	GRS-LEO	2	1
	EO-5	EO-5C EO-5D	EO-10	.4	APPLICATIONS EXPLORER	.2 .2	SPECIAL PURPOSE SAT. 'C' SPECIAL PURPOSE SAT. 'D'	4	2
NON-TUG LCE SUBTOTALS				0.9		1.4	EQUIV SHUTTLE FLIGHTS ______ 3.2	6	3
CDR	AST-6	AST-6	AS-01 *	1	LARGE SPACE TELESCOPE	1	LST	2	1
	AST-1	AST-1A	AS-03	.3	ASTRONOMY EXPLORER	.3	EXPLORER LEO COSMIC BACKGROUND	4	3
	AST-9	AST-9B AST-9A	HE-01 HE-11	1	X-RAY ASTRONOMY	1.0	LARGE TEL. FACILITY LHEO 'D' (1.2m X-RAY TELESCOPE)	3	3
	AST-5	AST-5	HE-03 HE-05 HE-06 HE-10	1	HIGH ENERGY ASTRONOMY	1	EXTENDED X-RAY SURV. HI-LATITUDE COSMIC RAY SURVEY LHEO 'A' (GAMMA RAY) LHEO 'C' (NUCLEAR CALORIMETER)	3	4
	PHY-1	PHY-1A	HE-07	.3	PHYSICS EXPLORER	0.3	SMALL HI-ENERGY SAT.	2	2
	PHY-5	PHY-5	HE-12	1	COSMIC RAY LABORATORY	1	COSMIC RAY LAB.	1	1
	AST-7	AST-7	SO-02	1	SOLAR ASTRONOMY	1	LARGE SOLAR OBSERVATORY	1	1
	AST-3	AST-3	SO-03	1	SOLAR PHYSICS	1	SOLAR MAXIMUM MISSION	1	1
	ST-1	ST-1	ST-01	1	SPACE ENVIRONMENT TECHN.	1	LONG DURATION EXPOSURE FACILITY	2	1
NON-TUG CDR SUBTOTALS				7.6		7.6	EQUIV SHUTTLE FLIGHTS ______ 34.3	19	17
CDE	EOP-6	EOP-6A EOP-6B EOP-6C	OP-03 *	1	MINILAGEOS	1	MINILAGEOS 28.5 INCL 55.0 INCL 90.0 INCL	6	1
NON-TUG CDE SUBTOTALS				1		1	EQUIV SHUTTLE FLIGHTS ______ 0.6	6	1
NON-TUG SUBTOTALS				14.5		15	EQUIV SHUTTLE FLIGHTS ______ 75.5	50	35

* REPRESENTATIVE PAYLOADS

DOD SPACECRAFT

		DOD DOD-IUS HEO LEO			
DOD SUBTOTALS				EQUIV SHUTTLE FLIGHTS 155	

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UIP	FLIGHT SCHEDULE & TYPE (D = DELIV. V = VISIT R = RETRIEVAL S = SORTIE /N = EQUIV SHUTTLE FLIGHTS)														
NITS	80	81	82	83	84	85	86	87	88	89	90	91	D	V	R
		D/1 D/.3	R/1 2D-2R/1.2	D/1 R-D/1	V/.5 D-R/1 4D-2R/1.8	V/.5 D/.5 D-R/1 2R-2D/1.2	R/.5 D/.5 D-R/1 2R-D/.9 3D/1.2 3D/.9	D/.5 R/.5 D-R/1 2D-2R/1.2 3R/1,2	V/.5 D-R/1 2R-2D/1.2 3D/.9	D/.5 R/.5 D-R/1 2R-2D/1.2 3R/.9	V/.5 D/.5 2R-2D/1.2 3D/1,2 3D/.9	R/.5 D/.5 D-R/1 2R-2D/1.2 3R/.9	2 2 3 9 20 6 9	2 0 2 0 0 0 0	3 1 1 8 18 3 6
		1.3	2.2	2	3.3	3.2	5	4.4	3.6	4.1	4.3	4.1	51	4	40
				D/1	D/1			D/.3	D/.3		D/.3	D/.3	2 2 2	0 0 0	0 0 0
				1	1			.3	.3		.3	.3	6	0	0
	D/.4 D-R/1.6	D/.4 D/.3 D-R/.6	D/.5 R/.4 R-D/.6 D/.3	R/.5 D/.3 D/.4 V/.2	V-D/.7 V/.2 R-D/.6 R-D/.6 D-R/1.6	R-D/1 D/.4 V/.2 V/.2 D/1	V/.2 D/.5 R/.4 D/.5 V/.3 D/.3 D-R/1.6	V/.2 R/.3 V/.2 D/.3 D/.4 V/.3	R-D/1 R-D/.8 V/.3 V/.2 D/.3 V/.2 V/.3 R-D/.6 D-R/1.6	V/.2 D/.4 V-R/.7 R-D/.6 V/.2 V/.3 R-D/1.6	V/.2 D/.4 V/.3 R-D/.6 V/.3 R-D/.6 D-R/1.6	V/.2 D-R/1 D/.3 R/.3 R-D/.6 V/.2 V/.3	4 6 2 1 1 1 1 1 6 1 1 6 7	6 0 2 2 1 0 2 1 0 3 6 0 1	3 2 1 1 1 0 1 1 4 0 0 5 6
9	2	1.3	1.8	1.4	3.7	2.8	3.3	1.7	5.3	4	4	2.9	38	24	25
5						2D/.2 2D/.2 2D/.2							2 2 2	0 0 0	0 0 0
5						0.6							6	0	0
4	2	2.6	4	4.4	8	6.6	8.3	6.4	9.2	8.1	8.6	7.3	101	28	65

	3.5	4.5	[illegible]	2 11	5 11	8 9	8 7	13 3	6 9	6 10	9 8	9 8	79 76		
	3.5	4.5	5	13	16	17	15	16	15	16	17	17	155		

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NASA & NON-NASA/NON-DOD HIGH ENERGY ORBIT SPACECRAFT

Table 4-7. Study Payl

GROUP	PAYLOAD MODEL NO.	TRAFFIC MODEL NO.	SSPD NO.	PROGRAMS QTY	PROGRAMS NAME	SPACECRAFT DDT&E	SPACECRAFT NAME/TYPE
TUG LCR	EOP-9	EOP-9	OP-06 *	1	MAGNETIC FIELD PHYSICS	1	MAGN. FIELD MONITOR
	NN D-8	NN D-8	EO-56	1	ENVIRONMENTAL MONITORING	1	ENVIRONMENTAL MONITORIN
	NN D-3	NN D-3	CN-54	1	DISASTER WARNING	1	DISASTER WARNING SATELLITE
TUG LCR SUBTOTALS				3		3	EQUIV SHUTTLE FLIGHTS
TUG LCE	PHY-1	PHY-1C	AP-03 *	.3	PHYSICS EXPLORER	1	HI-ALTITUDE EXPLORER
	PHY-2	PHY-2B	AP-06	.3	GRAVITY & RELATIVITY	0	GRS - SOLAR
	EO-7	EO-7	EO-07	1	U. S. SYNCH METEOROLOGY	1	ADVANCED SYNC METEOROLO
		EO-5A				.2	SPECIAL PURPOSE SAT. 'A'
	EO-5	EO-5B	EO-10	.6	APPLICATIONS EXPLORER	.2	SPECIAL PURPOSE SAT. 'B'
		EO-5E				.2	SPECIAL PURPOSE SAT. 'E'
	NN D-2	NN D-2A	CN-52	.3	U.S. DOMESTIC COMMUNICATIONS	[illegible]	DOMSAT 'A'
	NN D-4	NN D-4	CN-55	1	TRAFFIC MANAGEMENT	1	TRAFFIC MANAGEMENT SATEL
	NN D-6	NN D-6	CN-59	1	COMMUNICATIONS R&D	1	PROTOTYPE SAT.
TUG-LCE SUBTOTALS				4.7		4.6	EQUIV SHUTTLE FLIGHTS
TUG CDR	NN D-2	NN D-2C	CN-58 *	.4	U.S. DOMESTIC COMMUNICATIONS	1	TDRS (U.S. DOMSAT 'C')
	AST-1	AST-1A	AS-02	.7	ASTRONOMY EXPLORER	0.7	EXTRA CORONA LYMAN ALPH
		AST-1B	AS-05				ADVANCED RADIO EXPL.
	AST-8	AST-8	AS-16	1	RADIO ASTRONOMY	1	LARGE RADIO OBSV. ARRAY(
		PHY-1A	AP-01	.4	PHYSICS EXPLORER	0.4	UPPER ATMOS. EXPL.
	PHY-1	PHY-1B	AP-02				MEDIUM ALT. EXPL.
	PHY-3	PHY-3A	AP-05			1	SAT. MISSION 'A'
		PHY-3B	AP-07	1	ENVIRONMENTAL PERTURBATION		SAT. MISSION 'B'
	EO-4	EO-4A	EO-09	1	SYNCHRONOUS EARTH OBSERV.		R&D SEOS
		EO-4B				1	OPER. SEOS
	EO-6	EO-6	EO-12	1	GLOBAL & LOCAL METEOROLOGY	1	OPER. TIROS
	NN/D-9	NN/D-9	EO-57	1	FOREIGN SYNCH. METEOROLOGY	1	FOR. SYNCH. MET. SAT.
	NN/D-10	NN/D-10	EO-58	1	SYNCH. OPERATIONAL METEOROLOGY	1	GEOS. OPER. MET. SAT.
	NN/D-12	NN/D-12	EO-59	1	SYNCH. EARTH RESOURCES	1	GEOS. EARTH RESOURCES SAT
	NN/D-13	NN D-13	EO-62	1	FOREIGN SYNCH. EARTH OBSERV.	1	FOREIGN SEOS
	NN/D-1	[illegible]	CN-51	1	INTER[illegible]TION COMMUNICATIONS	1	INTELSAT
	NN/D-2	NN/D-2B	CN-53	.3	U. S. DOMESTIC COMMUNICATIONS	0	DOMSAT B
	NN/D-5	NN/D-5	CN-56	1	FOREIGN COMMUNICATIONS		FOREIGN COMSAT 'A'
			CN-60		FOREIGN COMMUNICATIONS	1	FOREIGN COMSAT 'B'
TUG CDR SUBTOTALS				11.8		12.1	EQUIV SHUTTLE FLIGHTS
TUG CDE	EOP-4	EOP-4	OP-01 *	1	EARTH-GR[illegible] USE	1	GEOPAUSE
	PHY-4	PHY-4	AP-08	1	MAGNETOSPHERIC PHYSICS	1	HELIOCENTRIC & INTERSTELLA
TUG CDE SUBTOTALS				2		2	EQUIV SHUTTLE FLIGHTS
TUG PLA.	PL-19	PL-19	PL-12 *	1	MARINER JUPITER ORBITER	1	LOW COST MODULAR 12-SIDE
	PL-7	PL-7	PL-01	1	MARS SURFACE SAMPLE RETURN	2.7	V075 + VL75 + MAV + PIONEER
	PL-8	PL-8	PL-02	1	MARS SATELLITE SAMPLE RETURN	1.7	V075 + SURVEYOR + PIONEER
	PL-10	PL-10	PL-03	.5	PIONEER VENUS MULTIPROBE	.2	PIONEER + ENTRY PROBE
	PL-11	PL-11	PL-07	1	VENUS ORBITAL IMAGING RADAR	1	VOIR - OCTAGONAL BUS
	PL-12	PL-12	PL-08	1	VENUS BUOYANCY PROBE	.4	MJS (1977, PL-5) + PROBE (RTG)
	PL-13	PL-13	PL-09	1	MERCURY ORBITER	.4	SEP, MJS
	PL-14	PL-14	PL-10	1	VENUS LARGE LANDER	.4	MARINER, VIKING LANDER
	PL-20	PL-20	PL-13	.5	PIONEER JUPITER PROBE	1.2	PIONEER + ENTRY PROBE
	PL-22	PL-22	PL-15	1	URANUS PROBE/NEPTUNE FLYBY	.4	FLYBY S/C (RTG'S)
	PL-27	PL-27	PL-19	1	HALLEY COMET FLYBY	.2	MJS
	PL-28	PL-28	PL-20	1	ASTEROID RENDEZVOUS	.4	S/C, SEP
	LUN-2	LUN-2	LU-01	1	LUNAR ORBITER	.4	MARINER, SUBSATELLITE
	LUN-3	LUN-3	LU-02	.5	LUNAR ROVER	1.2	SURVEYOR, ROVER
	LUN-4	LUN-4	LU-03	1	LUNAR HALO	.2	INTELSAT
	LUN-5	LUN-5	LU-04	.5	LUNAR SAMPLE RETURN	1.4	S/C, ROVER, SAMPLE RETURN
PLANETARY SUBTOTALS				14		13.2	EQUIV SHUTTLE FLIGHTS
TUG SUBTOTALS				35.5		34.9	EQUIV SHUTTLE FLIGHTS
TOTAL AUTOMATED SPACECRAFT				[51]	[DoD INCLUDED]	[49.9]	EQUIV SHUTTLE FLIGHTS

* REPRESENTATIVE PAYLOADS

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		MISSION EQUIP		FLIGHT SCHEDULE & TYPE (D - DELIVERY, V = VIST, R = RETRIEVAL /N = EQUIV SHUTTLE FLIGHTS)														
	UNITS	DDT&E	UNITS	80	81	82	83	84	85	86	87	88	89	90	91	D	V	R
IG SAT	1 2 3	2	3 4		D/.4	D/.3 D/.4		R/.3 2R/.8	D/.4 D/.4	D/.3 D/.4	R/.3 R-D/.8 R/.4	R-D/.8	R/.4	D-R/.8 D/.4	D/.4	2 6 4	0 0 0	2 6 1
8	6	6	8		.4	.7		1.1	.8	.7	1.5	8	4	1.2	.4	12	0	9
GICAL SAT. LITE	5 2 1 1 1 3 2 6 3	1 1 1 1 1 1 1 2 2	5 2 1 1 1 3 2 6 3			D/.6 D/.4 D/.4	D/.5 D/.4 D/.4	D/.6 D/.5 D/.4	D/.4 D/.5	D/.6 D/.4 D/.4	D/1 D/.3	D/.6 D/.4 D/.5	D/.6 D/.4	D/.4 D/.5	D/1	5 2 1 1 1 3 2 6 3	0 0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0 0
12.2	24	11	24			1.4	1.3	1.5	.9	1.4	1.3	1.5	1	0.9	1	24	0	0
A EXPL. ROA) ELLITE	6 5 2 1 3 1 7 1 3 2 4 4 10 11 6	1 .7 1 .4 1 1 1 1 1 1 1 1 1	6 5 2 2 3 2 7 1 6 6 4 4 10 11 9		D/.3 D/.3 D/.3 D/.4	D/.3 D/.3 D/.4	3D/.3 D/.3 D/.5 D/.5 D/.3 D/.3 2D/.8 D/.4	D/.3 R-D/1 R/.5 R/.4 D/.3 2R/.6 3D/1.2 D/.3 R-D/.8	D/.5 D/.5 D/.6 D/.3 R/.3 D-R/.6 2D/.8 D/.3 R/.4 D/.3	D/.3 R/.5 R/.3 D-R/.6 2D/.8 D/.3	RD/.6 D/.5 V/.5 D/.5 D/.5 2D/.5 D/.4 R-D/.6 R/.4 2D/.6 D/.3	3D/.3 R-D/.6 D/.3 2D/.7 D/.5 R/.4 3D/.9 R/.4 R/.3	V/.5 R-D/.6 2D/.5 RD/.6 2D/1 2D-2R/1.6 2D/.6 R-D/.6	R/.5 R-D/1 R-D/.6 2D/.7 3D-3R/2.4 2D/.6 D/.4 R/.3	R-D/.6 V/.5 RD/1 2D/.5 D-R/.6 D/.5 2D/.8 RD/.6	6 7 4 1 2 3 0 2 2 6 1 6 7 4 4 16 11 5 5	0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 2 2 0 1 2 1 1 1 0 1 4 6 0 0 7 0 3 4
51.3	66	28	78		1.3	1	6.1	5.4	4.6	2.8	5.4	7.1	6	6.5	5.1	92	3	35
R S/C	1 1	1 1	1 1			D/1						D/1				1 1	0 0	0
2	2	2	2			1						1				2	0	0
D S/C(RT) + EEC + EEC & SCI PACK S/C	2 2 2 2 2 2 2 2 2 2 1 2 2 2 1 2	1 1 1 1 1 1 1 1 1 1 1 1 1 .5 .2 .5	2 2 2 2 2 2 2 2 2 2 1 2 2 2 1 2		2D/2		D/1 2-D/2	2D/2 2D/2 D/1	2D/2 D/1	D/1 2D/2 2D/2 D/1	2D/2 D/1	D/1	2D/2 D/1	D/1 D/1	D/1 D/1	2 2 2 2 2 2 2 2 2 2 1 2 2 2 1 2	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
30	30	14.2	30		2		3	5	3	6	3	1	3	2	2	30	0	0
103.5	128	61.2	142		3.7	4.1	10.4	13	9.3	10.9	11.2	11.4	10.4	10.6	8.5	160	3	44
334	[178]	[96.2]	[196]	5.5	10.8	13.1	27.8	37	32.9	34.2	33.6	35.6	34.5	36.2	32.8	[261]	[31]	[109]

NASA AND NON-NASA/NON-DOD SORTIES

Table 4-7. Study Payloa

GROUP	PAYLOAD MODEL NO.	TRAFFIC MODEL NO.	SSPD NO.	PROGRAMS QTY	PROGRAMS NAME	SORTIE PAYLOADS TYPE	SORTIE PAYLOADS NAME
SORTIE I	AS-10	AST-10a thru AST-10m	AS-01 *	1	CRYOGENICALLY-COOLED IR ASTRON	PALLET	SIRTF - IR TELESCOPE
			AS-20			PALLET	2.5 m TELESCOPE
			AS-03	1	UV ASTRONOMY	PALLET	DEEP SKY SURVEY
			AS-04			PALLET	1 m DIFFRACTION LIMITED
			AS-19			PALLET	DEEP SKY SELECTION AREA SU
			AS-06	1	ASTRONOMICAL FLUX CALIBRATION	PALLET	1 m UV/IR SPECTR.
			AS-07	1	COMETARY INVESTIG.	PALLET	COMETARY SIMULATION
			AS-10	1	XUV ASTRONOMY	PALLET	ADVANCED TELESCOPE
			AS-11	1	EMISSION & ABSORPTION MEASUREMENTS	PALLET	POLARIMETRIC EXPERIMENTS
			AS-12	1	ATMOSPHERIC METEOROID INVESTIG	PALLET	METEOROID SIMULATION
			AS-14	1	AMBIENT IR ASTRONOMY	PALLET	1 m IR TELESCOPE
			AS-15			PALLET	3 m IR TELESCOPE
			[illegible]	.1	COMBINED PROGRAMS	PALLET	(AS-01,03,04,05) IR/UV
			AS-50	.1	COMBINED PROGRAMS	PALLET	(AS-04, 10) UV/XUV
			AS-51	.1	COMBINED PROGRAMS	PALLET	(AS-01, 15) IR
			AS-54	.1	COMBINED PROGRAMS	PALLET	(AS-03, 04) UV
	PHY-6	PHY-6a thru PHY-6e	HE-11	1	X-RAY ASTRONOMY	PALLET	X-RAY ANGULAR STRUCTURE
			HE-19			PALLET	LOW ENERGY X-RAY
			HE-20			PALLET	HIGH RESOLUTION IMAGING
	AST-11	AST-11 a - e	SO-01	1	SOLAR ASTRONOMY	PALLET	DSSM
			SO-11			PALLET	FINE POINTING
			SO-12			PALLET	ATM SPACELAB
SORTIE I SUBTOTALS				10.4			EQUIV SHUTTLE FLIGHTS
SORTIE II	PHY-7	PHY 7 a-e	AP-06 *	1	ATMOSPHERIC & SPACE PHYSICS	M+P	AMPS
	AST-101	AST-10 a-m	AS-09	1	IR INTERFEROMETER	PALLET	30M
			AS-18			PALLET	1.5M
	LS-2	LS-20	LS-04	1	BIOTECHNOLOGY	M+P	TELEOPERATOR
SORTIE II SUBTOTALS				3			EQUIV SHUTTLE FLIGHTS
SORTIE III	ST-2	ST-2 a-d	ST-23 *	.3	ADVANCED TECHNOLOGY	PALLET	ATL # 5
	PHY-6	PHY 6 a-e	HE-15	1	MAGNETIC SPECTROMETER	PALLET	MAGNETIC SPECTROMETER
	EOP-10	OA-1 a, b	OP-02	.5	RADAR LAND IMAGERY	M+P	MULTIFREQ. RADAR LAND IM
	EOP-10		OP-03	1	MICROWAVE RADIOMETRY	M+P	MICROWAVE RADIOMETER
	EOP-10		OP-04	1	MICROWAVE SCATTEROMETER	PALLET	MICROWAVE SCATTEROMETER
	EOP-10		OP-05	.5	MULTI-SPECTRAL SCANNING IMAGERY	M+P	MULTISPECTRAL SCANNING I
	EOP-10		OP-06	1	LASER PHYSICS	M+P	COMBINED LASER EXPERIMEN
	SP-1	SP-1 a-c	SP-12/19	1	SPACE PROCESSING	M+P	SPA # 12- # 19
	ST-2	ST-2 a-d	ST-21	.7	ADVANCED TECHNOLOGY	M+P	ATL # 2
			ST-22			M+P	ATL # 3
	EO8	OA-1 a,b	EO-05	1	IMAGING MICROWAVE	PALLET	SIMS
	CN-3	NN/D-16	CN-04/06	1	COMMUNICATIONS & NAVIGATION	M+P	TERRESTRIAL NOISE & INTERFI
			CN-07			M+P	LASER/COMMUNICATIONS R
			CN-08, 11, 12			PALLET	LARGE REFLECTOR DEPLOYME
						M+P	TWT's/ATT. DETERM./INTERF.
SORTIE III SUBTOTALS				9			EQUIV SHUTTLE FLIGHTS
IV	ST-2	ST-2 a-d	ST-04 *	1	PHYSICS & CHEMISTRY	MODULE	WALL-LESS CHEM
			ST-06			MODULE	FLUID PHYSICS
SORTIE IV SUBTOTALS				1			EQUIV SHUTTLE FLIGHTS
NASA SORTIE PAYLOADS				23.4			EQUIV SHUTTLE FLIGHTS
	NN/D-15	NN/D-15	—	1	SPACE MANUFACTURING		
	—	—		1	ESRO		
ESRO SUBTOTALS				2			EQUIV SHUTTLE FLIGHTS

* REFERENCE PAYLOAD

FOLDOUT FRAME

d Model Sheet 3 of 3

	PAYLOAD EQUIV.	MISSION EQUIP		FLIGHT SCHEDULE TYPE D = DELIVERY (P/L TO ORBIT) N/N – DELIVERY TO ORBIT/EQIV. SHUTTLE FLIGHTS													
		DDT&E	UNITS	80	81	82	83	84	85	86	87	88	89	90	91	D	DAYS
RVEY	.5 .75 .5 .4 .4 .5 .4 .4 1 1 .5	1 .3 1 1 1 1 1 1 1 .5 .1 .1 .1 .1 2 1 .2	2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2	1/.7	1/.7	1/7 1/.5 1 .7 - 1/.9	1/7 1/.8 1 7 1 6 1/9 1 8	1/1 1/.5 1/.5 1/.6 1/.7 2/2	1/6 1/1 1/7 1/8 1/.7 1 .9 1. 8 1/1	1.8 + 1/6 1/1 1/ 7 + 1/.6 1/.7 1.8 1/1	1/.7 1/.9 1/.9 1/.7 + 1/ 6 1/.9 1/.8 1/1	1/.7 + 1/.8 1/1 1/.5 + 1/.5 + 1/.7 + 1 .7 + 1/.9 + 1/.8	1/1 1/7 + 1/.8 + 1 .7 + 1 .6 + 1/.7 + 1.9 1/ 8 + 1/1 +	1/.8 + 1/.6 + 1/1 + 1/.7 1/.9 1/.9 1/.6 + 1/.7 + 1/.9 1/1 +	1/.7 + 1/.5 + 1/.7 1/.9 1/.9 1/.7 1/.9 1/.8 + 1/1 +	4 2 2 2 3 2 2 2 2 2 2 2 2 2 2 3 3 7 6 7 8 7 8	74 60 14 37 44 14 14 37 37 14 37 37 37 14 21 21 141 88 118 79 95 125
62.2		12.6	29	.7	.7	2.8	4 5	5.3	6.5	6.2	6.5	6.6	7.2	8.1	7.1	80	1158
	1 .5 .2 .2	1 1 1 1	3 1 1 1		1/1 2/1.6	1/1 2/1.6	2/2	3/3 1/.7	2/2 1/.9	2/2	3/3	1/.7	3/3 1/9	2/2	2/2	21 2 2 4	147 14 14 28
27.4		4	6		2.6	2.6	2	3./	2.9	2	3	0.7	3.9	2	2	29	203
AGERY MAGERY TS ERENCE ELAY NT NAV.	1 .3 .5 .3 .5 .5 .3 17 .7 .6 .3 .6	1 1 .6 1 1 .5 1 1 .1 .1 1 3 1 3	2 2 2 1 1 2 3 6 3 2 1 3 3 3	1/.5 1/.5 1/.5	1/1 1/.8	1/5 3/2.1 1/1 1/8	1 7 1/.5 1/.7 2/2 1/1 1/1	1/.7 1/.3 1/.5 1/.7 3/3 1/1 1/.8 1/1	1/1 2/1.4 1/.3 1/.3 1/.5 2/1.4 1/1 1/1 1/8 1/.8	1/1 1/.5 1/.5 2/1.4 1/1 1/.8 1/1	1/1 1/.7 1/.5 1/.5 1/.3 1/.3 1/.5 2/1.4 1/1 1/1 1/.8 1/1	1/1 1/.7 1/.5 1/.5 1/.3 1/.3 3/1.5 3/2.1 1/1 1/1 1/.8 1/.8	2/2 1/.5 1/.5 1/.3 1/.3 1/.5 5/3.5 1/1 1/1	2/2 1/.7 1/.5 1/.5 1/.3 1/.3 1/.5 1/.7 1/1 1/1 1/.8	1/1 1/.7 1/.5 1/.5 1/.3 1/.3 1/.5 3/2.1 1/1 1/1 1/1	9 8 8 8 6 7 10 23 9 9 3 5 5 6	63 56 56 56 42 49 70 161 63 63 21 35 35 42
82.6		15.3	34	1.5	1.8	4.4	5.9	8	8.5	6.2	9	10.5	9.6	8.3	8.9	116	812
	1 .3	1 1	2 1			1/1			1/1	1/1	1/1	1/1 1/.2	1/1 1/.2	1/1	1/1	8 2	56 14
8.4		2	3			1			1	1	1	1.2	1	1	1	10	70
180.6		33.9	71	2.2	5.1	10.8	12.4	17	18.9	15.4	19 5	19	21.9	19.4	19	235	2193
				1/.3	2/1				2/.6 3/3	4/2.5 4/3	2/1 3/3	1/.3 6/4	5/4	5/3	5/4	9 34	63 238
29.7				.3	1				3.6	5.5	4	4.3	4	3	4	43	301

+ 30 DAY FLIGHT

FOLDOUT FRAME 2

4.3 ROUTINE OPERATIONS COST EXTRAPOLATION

Routine baseline payload costs and EVA cost savings data were prepared in detail from the costing analysis performed on each representative payload. Taking the spacecraft, mission equipment, and orbital support unit cost savings separately, and assigning a technical complexity factor based on engineering evaluation, each represented payload was considered separately. The number of programs, spacecraft units, and varying scientific objectives over a number of launches were derived from the payload model analysis. Where more than one unit was required, learning factors were also applied. A sample of the details of the Study Model costing are contained in Table 4-8, which takes into account each defined program, spacecraft and mission equipment development/procurement, orbital support unit, as well as weight and complexity factors which were based on detailed technical evaluations.

Table 4-8. Sample Cost Extrapolation Input Data

Spacecraft	Weight (K-kg)	Complexity Factor*	Program	No. of New S/C	Refurb. S/C	New Mission Equip.	Year											
							80	81	82	83	84	85	86	87	88	89	90	91
EOS (EO-08)	3.9	1.0	1	3	4	4		D	R	D	V	D/V	D/R	D/R	V	D/R	V	D/R
ERS (EO-61)	4.3	1.2	1	2	8	2				R/D	D/R	D/R	D/R	D/R	D/R	D/R	D	D/R
BESS (LS-02)	0.35	0.8	1	5	18	5		D	D/R		D/R	D/R	D/R	D/R	D/R	D/R	D/R	D/R
VMS (OP-05)	0.6	0.3	1	3	3	3							D	R			D	
GEOM (OP-51)	2.5	0.6	1	6	3	6							D		D	R	D	R

D - Delivery
R - Retrieval
V - Planned visit
* - Relative to representative spacecraft

Table 4-9 reflects the baseline design, development, test and engineering (DDT&E) and theoretical first unit (T1) cost for each representative payload; the EVA savings estimated for the representative payload DDT&E and first unit; the number of DDT&E programs and total quantity of equivalent flight units required for the payload, based on the traffic model (Table 4-7). From these data, the total estimated savings are calculated for DDT&E and the recurring quantity of flight units forecasted.

The baseline and EVA savings DDT&E and T1 are taken directly from the CAM IV output tab runs and rounded to the nearest $100,000.

4.3.1 Extrapolation Methodology

The quantities for DDT&E programs and number of flight units are based on the traffic model. The number of programs are taken directly from Table 4-7 (reflecting an evaluation described earlier). The flight unit quantities were determined by application of technical complexity factors to the number of required units in order to develop *equivalent* units. (See Table 4-8.) As an example, the traffic model for EOS and its represented group is reflected in Table 4-10.

Table 4-9. EVA Study - Summary of Extrapolated Routine Operations Savings

Payload/Elements	Representative Payloads				Program Model Extrapolation			
	Baseline Design Total $M		Net Savings $M		Equivalent Quantity		Total Savings $M	
	DDT&E	First Unit	DDT&E	First Unit	Programs	Units	DDT&E	Recur
Earth Observatory Satellite								
Spacecraft Systems	26.6	12.8	0.6	0.2	5	14	3.1	3.3
Mission Equip	62.6	31.5	0.1	0.1	5	15	0.5	0.6
Orbital Support Unit	6.0	4.6	0.5	0.1	5	5	2.3	0.8
Other Costs	75.3	13.7	0.6	0.1	–	–	3.1	1.2
Total	170.5	62.6	1.8	0.5	–	–	9.0	5.9
Gravity and Relativity Satellite								
Spacecraft Systems	5.8	2.4	0.6	0.2	1	6	0.6	0.9
Mission Equip	11.8	6.5	0.1	–	1	6	0.1	0.2
Orbital Support Unit	1.2	0.5	0.4	0.1	2	2	0.5	0.2
Other Costs	14.9	2.7	0.5	0.1	–	–	0.6	0.4
Total	33.7	12.1	1.6	0.4	–	–	1.8	1.7
Large Space Telescope								
Spacecraft Systems	36.5	19.0	1.4	0.5	8	14	10.9	6.9
Mission Equip	26.1	19.4	–	–	8	14	–	–
Orbital Support Unit	9.0	5.5	6.2	4.0	9	9	55.7	36.3
Other Costs	52.8	11.8	1.2	0.2	–	–	9.2	2.1
Total	124.4	55.7	8.8	4.7	–	–	75.8	45.3
Minilageos								
Spacecraft Systems	–	–	–	–	–	–	–	–
Mission Equip	0.4	0.1	–	–	1	6	–	–
Orbital Support Unit	1.3	0.3	0.1	0.1	1	1	0.1	0.1
Other Costs	0.3	–	–	–	–	–	–	–
Total	2.0	0.4	0.1	0.1	–	–	0.1	0.1
Magnetic Field Monitor								
Spacecraft Systems	5.2	2.3	0.4	0.1	3	6	1.1	0.8
Mission Equip	0.4	0.1	–	–	3	8	–	–
Orbital Support Unit	1.5	1.4	0.2	0.1	3	3	0.7	0.2
Other Costs	4.8	0.7	0.3	–	–	–	0.9	0.3
Total	11.9	4.5	0.9	0.2	–	–	2.7	1.3
High Altitude Explorer								
Spacecraft Systems	7.8	3.6	–	–	5	24	0.1	0.1
Mission Equip	1.9	0.6	0.1	–	5	24	0.4	0.8
Orbital Support Unit	1.2	0.4	0.1	–	7	7	1.0	0.2
Other Costs	8.2	1.3	0.1	–	–	–	0.5	0.2
Total	19.1	5.9	0.3	0.1	–	–	2.0	1.3
DOMSAT "C"								
Spacecraft Systems	4.9	2.0	0.1	0.1	12	62	1.2	4.2
Mission Equip	3.9	2.9	0.3	0.1	12	74	3.6	7.0
Orbital Support Unit	0.8	0.5	–	–	14	14	(0.1)	(0.2)
Other Costs	7.4	1.5	0.3	–	–	–	4.1	3.5
Total	17.0	6.9	0.7	0.2	–	–	8.8	14.5
Geopause								
Spacecraft Systems	10.6	5.2	0.1	–	2	2	0.2	0.1
Mission Equip	4.8	3.1	0.1	–	2	2	0.2	0.1
Orbital Support Unit	1.2	0.5	0.5	0.2	2	2	1.1	0.4
Other Costs	13.0	2.6	0.2	–	–	–	0.4	–
Total	29.6	11.4	0.9	0.2	–	–	1.9	0.6
Mariner Jupiter Orbiter								
Spacecraft Systems	15.0	10.2	0.2	<0.1	14	30	2.5	1.8
Mission Equip	0.7	0.2	–	–	14	30	–	–
Orbital Support Unit	3.0	1.1	0.7	0.2	16	16	10.9	2.4
Other Costs	13.3	3.2	0.1	–	–	–	2.1	0.5
Total	32.0	14.7	1.0	0.3	–	–	15.5	4.7

Table 4-9. EVA Study - Summary of Extrapolated Routine Operations Savings (cont.)

	Representative Payloads				Program Model Extrapolation			
	Baseline Design Total $M		Net Savings $M		Equivalent Quantity		Total Savings $M	
Payload/Elements	DDT&E	First Unit	DDT&E	First Unit	Programs	Units	DDT&E	Recur
Shuttle Infrared Telescope Facility								
Mission Equip	31.9	10.6	3.1	0.8	10	35	31.4	27.7
Other Costs	27.0	3.3	2.7	0.2	-	-	26.5	8.5
Total	58.9	13.9	5.8	1.0	-	-	57.9	36.2
Atmospheric, Magnetospheric and Plasmas in Space								
Mission Equip	59.3	104.2	3.0	1.1	4	5	12.1	5.3
Other Costs	50.1	32.1	2.6	0.3	-	-	10.2	1.6
Total	109.4	136.3	5.6	1.4	-	-	22.3	6.9
Advanced Technology Laboratory								
Mission Equip	60.2	29.6	6.3	1.6	15	20	94.5	39.7
Other Costs	50.8	9.1	5.3	0.5	-	-	79.7	12.2
Total	111.0	38.7	11.6	2.1	-	-	174.2	51.9
Physics and Chemistry Facility								
Mission Equip	15.0	5.9	3.3	1.2	1	2	3.4	2.3
Other Costs	12.7	1.8	2.8	0.4	-	-	2.8	0.7
Total	27.7	7.7	6.1	1.6	-	-	6.2	3.0
Spacecraft Totals								
Spacecraft Systems	112.4	57.5	3.4	1.2			19.7	18.1
Mission Equip	112.6	64.4	0.7	0.2			4.8	8.7
Orbital Support Unit	25.2	14.8	8.7	4.8			72.2	40.4
Other Costs	190.0	37.5	3.3	0.4			20.9	8.2
Total	440.2	174.2	16.1	6.6			117.6	75.4
Sortie Totals								
Mission Equip	166.4	150.3	15.7	4.7			141.4	75.0
Other Costs	140.6	46.3	13.4	1.4			119.2	23.0
Total	307.0	196.6	29.1	6.1			260.6	98.0
Totals								
Spacecraft Systems	112.4	57.5	3.4	1.2			19.7	18.1
Mission Equip	279.0	214.7	16.4	4.9			146.2	83.7
Orbital Support Unit	25.2	14.8	8.7	4.8			72.2	40.4
Other Costs	330.6	83.8	16.7	1.8			140.1	31.2
Total	747.2	370.8	45.2	12.7			378.2	173.4

	Program Total Costs - $M			Program EVA Savings	
	DDT&E	Recurring	Total	Amount $M	Percent
System Elements					
Spacecraft Systems	775.4	980.4	1755.8	37.8	2.2
Mission Equip	2092.9	2471.0	4563.9	229.9	5.0
Orbital Support Unit	189.2	106.4	295.6	112.7	38.1
Other Costs	2422.1	1062.8	3484.5	171.2	4.9
Total	5479.6	4620.6	10099.8	551.6	5.5

Table 4-10. Typical (EOS) Payload Group Extrapolation Data

Payloads	No. Prog.	Technical Complexity	S/C and Subsystems Units	S/C and Subsystems Equiv. Units	Mission Equip. Units	Mission Equip. Equiv. Units
EOS (EO-08)	1	1.0	3	3.0	4	4.0
ERS (EO-16)	1	1.2	2	2.4	2	2.4
BESS (LS-02)	1	0.8	5	4.0	5	4.0
VMS (OP-05)	1	0.3	3	0.9	3	0.9
GEOM (OP-51)	1	0.6	6	3.6	6	3.6
TOTAL	5		19	13.9	20	14.9
Used (Rounded)				14		15

In this example, each payload was considered to require a separate development program. The complexity factor is by comparison to the EOS (representative payload), which is unity. The number of spacecraft units was conservatively derived as reflecting the minimum necessary to support the flight schedule. In this case, as for some other groups, the mission equipment quantity was larger to reflect an expected development upgrading.

The total DDT&E savings were developed by extending the representative payload DDT&E savings (unrounded) for all elements [spacecraft systems, mission equipment (M.E.), orbital support equipment and other cost] by the number of programs projected. It should be noted that only mission equipment and other costs were calculated on sortie payloads.

The recurring or flight unit savings were extrapolated from T1 savings for all elements except orbital support equipment, by the use of 98-percent cost reduction curve for every two units required, multiplied by the total quantity. Orbital support unit savings were determined by extending the unit recurring savings by the program or DDT&E quantity without application of learning. This is done on the technical evaluation that each program's OSU requires unique development, and on the conservative assumption that only one unit is required to support the traffic model. This rationale permits reuse of orbital support equipment because of gaps between flights.

An example of the technique used to project total savings is reflected below and on the following page.

EOS Group Cost Elements	No.
Number of programs	5
Number of equivalent units of new spacecraft systems	14
Number of equivalent units of new mission equipment	15
Number of new orbital support equipment units	5

EOS Representative Payload Savings	T1	DDT&E
Flight systems (less M.E.) - baseline	12.788	26.609
Flight systems (less M.E.) - EVA	-12.548	-25.993
Net savings - each	0.240	0.616
Mission equipment - baseline	31.542	62.601
- EVA	-31.503	-62.496
Net savings - each	0.039	0.105
Orbital support equipment - baseline	4.552	5.989
- EVA	- 4.402	- 5.521
Net savings - each	0.150	0.468
Other costs - baseline	13.654	75.295
- EVA	-13.568	-74.684
Net savings - each	0.086	0.611

PROGRAM ELEMENTS

	Qty.	SAVINGS Each	SAVINGS Total $M
DDT&E - Non-Recurring			
Subsystems	5	0.616	3.08 (3.1)
Mission Equipment	5	0.105	0.525 (0.5)
Orbital Support Equipment	5	0.468	2.34 (2.3)
Other Costs	5	0.611	3.055 (3.1)
Total DDT&E Savings		1.800	9.0

Unit - Recurring

		Total Savings $M
Spacecraft - Subsystems		
T1	0.240	
CRC	98%	
Factor (for 2 units)	196%	
Cost 2 units	$ 0.470	
Total Cost 7.0 (14÷2)		3.290
Used		(3.3)
Mission Equipment		
T1	0.039	
CRC	98%	
Factor (for 2 units)	196%	
Cost 2 units	$ 0.076	
Total Cost 7.5 (15÷2)		0.570
Used		(0.6)

PROGRAM ELEMENTS (continued)

Orbital Support Equipment		Total Savings ($M)
T1	0.149	
Total for 5 units		0.745
Used		(0.7)

Other Costs

Total Support Systems & Mission Equipment	3.86	
Factor (30.8%) =		1.188
Used		(1.2)
		5.8

4.3.2 Summary of Routine Operations EVA Savings

Overall savings for the Study Payload Model totaled $551 million. This is a net savings out of a total of $10.1 billion established for the payloads in the study model by extrapolation from the representative payloads. To identify additional savings for non-NASA payloads, estimates were made for DOD spacecraft and non-NASA sorties by a simple ratio of flights, and do not reflect detailed technical nor cost analyses. These data are shown in Table 4-11.

Table 4-11. Routine EVA Net Cost Savings Summaries

	AUTOMATED S/C			SORTIE PAYLOADS		
	PROGRAMS	UNITS	$M	PROGRAMS	UNITS	$M
TOTAL STUDY MODEL NASA PAYLOADS • SAVINGS - $551 M	51	178	192	23	71	359
DOD SPACECRAFT • SAVINGS - $166 M	44	154	166			
NON-NASA SORTIE • SAVINGS - $59 M	-	-	-	4	11	59
TOTALS - $776 M	95	332	358	27	82	418

4.4 CONTINGENCY OPERATIONS COST SAVINGS ANALYSIS

4.4.1 Potential EVA Savings For All Contingencies

One of the benefits envisioned for provision of EVA operations on Shuttle orbiter flights is that of potential program savings through a capability of coping with payload contingencies after their delivery to orbit. The savings can be in terms of reduced transportation costs (orbiter flights) or experiment costs (loss of all or part of payload equipment). If an automated payload contingency occurred during or after delivery to Shuttle orbit, the contingency could require return of the spacecraft to earth for repair and a subsequent reflight. By definition, the contingencies could not have a pre-planned automated response, but EVA could provide the required repair capability on orbit and thus save the approximate $10 million cost of a subsequent Shuttle launch. Table 5-7 summarizes the potential EVA savings based on the contingency option.

If the contingency occurs on low earth orbit spacecraft after the orbiter has returned to earth, the repair and return of the spacecraft to operational status would then require two flights of the Orbiter to accomplish. The first flight would be required to retrieve the spacecraft and return it to earth; the second flight to deliver the payload to orbit again. The transportation cost for this sequence would then be $20 million. With an EVA mode of operation, a repair crew could be launched and accomplish payload repair on orbit after rendezvous with the disabled spacecraft. This would require only one extra flight of the orbiter, resulting in a net saving of $10 million compared with the baseline mode.

Table 4-12. Potential EVA Savings - Contingency Options

COSTS		BASELINE	EVA
TRANSPORTATION	DELIVERY MISSION	RETURN & REFLY: $10 M	REPAIR & DEPLOY: —
	S/C ON-ORBIT	LAUNCH / RETRIEVE / RELAUNCH: $20 M	LAUNCH / RETRIEVE / REPAIR / DEPLOY: $10 M
	SORTIE PAYLOAD EXPERIMENTS	RETURN / REFLY / EXPERIMENT: $3.5 M AVG	REPAIR/ CONTINUE MISSION: —
EXPERIMENT	AUTO S/C DELIVERY/ RETRIEVAL	JETTISON FAILED EXTENDABLE: $50 K AVG	MANUAL RETRACT / STOW: —
	SORTIE P/L PREPARE FOR RETURN	JETTISON FAILED EXTENDABLE: $1.7 M AVG	MANUAL / RETRACT / STOW: —

For sortie payloads the contingencies could be failure of a major experiment to function after the sortie flight arrives at the operational orbit. Analysis of representative payload groups shows an average cost penalty of \$3.5 million for such reflight. An EVA repair capability may allow immediate repair and compilation of the experiment program so that a subsequent flight is not required. The \$3.5 million cost was derived from the analysis of representative sortie payloads and extrapolation to the payload model. Thus, the Physics and Chemistry Facility (PCF) carries 4 unique experiments; cost of reflight of any one (assuming integration into a subsequent sortie) would be

$$\frac{\$10\text{M COST OF FLIGHT}}{4\text{ EXPERIMENTS}} = \$2.5\text{ million (average cost/flight/experiment)}$$

Each of the four sorties was similarly assessed, and taken as representative of their group. These numbers were then weighted as a function of the relative number of flights by each type of sortie. Again, using the PCF as an example:

$$\$2.5\text{M} \times \frac{10\text{ (P/L - FLIGHTS FOR PCF GROUP)}}{235\text{ (TOTAL SORTIE P/L FLIGHTS)}} = \$0.106\text{ million}$$

Based on these calculations, an overall average for the sortie model is \$3.5 million per experiment reflight.

Experiment equipment contingencies may include the failure of extended booms to retract, thus requiring jettisoning of the extended experiment in order to allow the orbiter to return to earth. Potential savings will average \$1.7M in jettisoned equipment if EVA could provide manual retraction and stowage, based on representative payload detailed cost analyses. Average costs of units extended beyond the Shuttle were derived in a similar manner to the average cost of reflight. Using the PCF again as an example, it has three extendible devices. The total recurring cost from the detailed cost analysis was \$2.7M for all three. Therefore, $\frac{\$2.7\text{M}}{3} = \$0.9\text{M}$, average cost of extendible for PCF

Each representative sortie was assessed in this manner. Again, each average value was then weighted as a function of its percent of missions out of the total sortie models, resulting in the average costs for sortie extendibles of \$1.7 million.

By extrapolating from these data to the overall mission model, approximately \$1.9 billion savings exist where EVA can be applied to prevent reflight and equipment losses. Based on the anomaly data extrapolated to the study traffic model from Table 4-12, the potential for significant EVA savings exists in the categories shown in Table 4-13.

The savings are based on the capability of retrieval for all spacecraft in the model (while in Shuttle orbit) and are based on a potential for repair by EVA, which may not exist in all cases.

Table 4-13. Contingency - Potential Cost Savings

AUTOMATED SPACECRAFT TRANSPORTATION		COST $M
• NASA	39 UNSUCCESSFUL DELIVERIES	390
	39 LEO RETRIEVALS (≤50% LIFE)	390
• DoD	23 UNSUCCESSFUL DELIVERIES	230
	29 LEO RETRIEVALS (≤50% LIFE)	290
SORTIE PAYLOADS		
• NASA	35 UNSUCCESSFUL PAYLOAD EXPERIMENTS	125
	215 FAILED EXTENSION ELEMENTS JETTISONED	367
• NON-NASA	6 UNSUCCESSFUL PAYLOAD EXPERIMENTS	11
	39 FAILED EXTENSION ELEMENTS JETTISONED	67
• TOTAL POTENTIAL FOR EVA SAVINGS		$1870M

4.4.2 Potential EVA Savings for Time-Critical Contingencies

Using the data in Section II, Table 2-7, on the probability of time-critical contingencies among the payloads with a possibility of occurrence, estimates were made of potential cost savings where there is a quick-reaction EVA capability to repair. The savings extrapolations were the same as for the overall contingency analysis discussed earlier, in terms of reflight costs avoided ($10 million/launch) if EVA repair can be effected before a critical point is reached. Missed launch windows should only require reflight about one-third of the time, based upon average number of available opportunities per mission.

Sortie reflight costs are again based on number of experiments. The ratio of early failures is based on the overall contingency analysis presented earlier. The potential cost savings as tabulated in Table 4-14 are $73 million for automated spacecraft (NASA and DoD) and $38 million for the sortie payloads, for a total of $111 million. Only NASA payloads were calculated on the basis of technical data. DoD and non-NASA sortie payloads were extrapolated from mission model data. It should be noted that this figure is conservative in comparison to the number of time-critical contingencies (15 percent) of all contingencies. By the same relationship, 15 percent of $1870 million would equal $281 million savings.

Table 4-14. Potential EVA Savings in Time-Critical Contingencies

POTENTIAL CONDITION	POTENTIAL SPACECRAFT W/ANOMALIES		NO. EARLY FAILURES(.024) S/C LOST/ANOM.		$M POTENTIAL COST/ANOM.		$M POTENTIAL SAVINGS	
	AUTO S/C + DoD	SORTIE P/L + NON-NASA	AUTO S/C	SORTIE P/L	AUTO S/C	SORTIE P/L	AUTO S/C	SORTIE P/L's
LOSS OF CONSUMABLES	64+39=103	58-10=68	2.5	1.6	10	10	25	16
LOSS OF BIOSPECIMENS	2+0=2	4+1=5	0.05	0.1	10	10	1	1
THERMAL PROBLEMS	79+47=126	56+9=65	3.0	1.6	10	10	30	16
MISSED LAUNCH WINDOW	132+78=210	---	5.0	---	3.3	---	17	---
MISSED TRACK OR TARGET	---	60+6=66	---	1.5	---	3.5	---	5
TOTALS	441	204	10.55	4.8	---	---	73	38
					TOTAL		$111 M	

4.5 EVA SAVINGS IN PLANNED MAINTENANCE

An analysis of automated versus EVA planned on-orbit maintenance was discussed in Section II. To compare these two modes, programmatic cost estimates were prepared. The comparative costs for automated methods and EVA were based only upon differences in transportation and equipment costs. Spacecraft in orbits directly achievable by the Shuttle (including the EOS) can be maintained with a single Shuttle launch in either mode; therefore, only support equipment costs are compared. At higher energy orbits, transportation costs become a factor. Equipment costs were derived on two representative payloads (EOS and LST) and extrapolated to spacecraft programs in the study model. To provide a broader base of data, programs and spacecraft identified in the model which have scheduled retrieval as well as maintenance were included as benefiting from a planned orbital maintenance. This was more significant in the HEO case, since only one program currently schedules planned maintenance. Each program was assumed to require its own DDT&E and first unit. Second units were added where servicing spanned over more than 5 years.

The listing in Table 4-15, reflects all payloads carried in the study payload model which were identified as requiring on-orbit maintenance. All spacecraft which identified planned retrieval missions, which certainly have on-orbit maintenance as a possible alternative, were included to increase the sample size for programmatic analysis.

Table 4-15. Candidate Planned Maintenance Payloads

Program Name and Eq. DDT&E		Spacecraft Type	Spacecraft No.	No. Retrievals	No. Visits	Years Spread
LOW EARTH ORBIT						
Earth Observatory	1	LCR	4	5	4	10
Large Space Telescope	1	CDR	2	3	6	9
X-Ray Telescope Fac.	0.5	CDR	2	1	2	5
Lg. Hi-Energy Ast.	1	CDR	4	3	4	8
Cosmic Ray Lab.	1	CDR	1	-	3	4
Lg. Solar Observatory	1	CDR	1	-	6	6
Lg. Duration Exp. Fac.	1	CDR	3	6	1	10
Earth Resource Surv.	1	LCR	3	8	-	8
Biol. Exp. SC Sat.	1	LCR	4	18	-	10
Vector Magn.	1	LCR	3	3	-	4
Earth & Ocean Mon.	1	LCR	6	6	-	5
LEO Explorer	0.3	CDR	3	2	-	10
Lg. Telescope Fac.	0.5	CDR	1	1	2	5
Hi-Energy Explorer	0.3	CDR	2	4	-	10
Solar Max.	1	CDR	3	5	-	9
HIGH EARTH ORBIT (Tug)						
Lg. Radio Astronomy	1	CDR	1	-	3	6
Magnetic Field Mon.	1	LCR	1	2	-	5
Environmental Monitor	1	LCR	1	6	-	9
Disaster Warning	1	LCR	3	1	-	9
Lyman Alpha Exp.	0.6	CDR	7	4	-	10
Physics Explorer	1/2	CDR	4	3	-	8
Envir. Perturbation	1	CDR	2	2	-	6
TIROS-O	1	CDR	1	1	-	3
Foreign Synch. Met.	1	CDR	6	4	-	9
Geos. Ops. Met. Sat.	1	CDR	2	6	-	10
Intelsat	1	CDR	10	7	-	8
Foreign Comsat	1	CDR	9	7	-	10
Synch. EOS	1	CDR	7	1	-	8

By taking cost data for Shuttle-installed maintenance equipment from the detailed representative payload cost analysis, comparative data were prepared. The cost of automated maintenance units were established at $7.5 million DDT&E, and $5 million first unit. The comparable EVA costs were $2.8 and $1.4 million, respectively. The LEO missions in the automated mode require $248 million for the support systems and the EVA $80 million, resulting in a net EVA savings of $168 million. The HEO mission base is more economical primarily due to the transportation cost. Table 4-16 summarizes these results.

Table 4-16. On-Orbit Planned Maintenance Savings

MISSION	MODE	COST $ M	
		SUPPORT SYSTEM	TRANSPORTATION
LEO	AUTO	248	
	EVA	80	
● EVA NET SAVINGS $ 168 M			
HEO	SHUTTLE ORBIT		
	AUTO	238	1128
	EVA	60	1128
	S/C ORBIT		
	AUTO	238	564
	EVA	235	1128
● EVA LESS ECONOMICAL THEN BEST CASE BASELINE.			

V. SPECIAL STUDY ISSUES

In the process of analyzing EVA design orientation, several issues were presented which, while not in the mainstream activity of the study, potentially could impact the validity of the study results. In some cases, these issues appeared to be negative relative to the appropriate use of EVA--for example, man-rating requirements, EVA contamination, availability of equipment and trained personnel. As a consequence, each of these factors was investigated. Additionally, two areas of EVA application were studied programatically in comparison to routine operations which were studied in detail. These are planned maintenance and contingency operations.

The planned maintenance analyses were limited to comparing automated on-orbit maintenance to EVA maintenance, rather than evaluating all forms of on-orbit and ground maintenance or expendable spacecraft trades.

The contingency analysis was performed to establish the potential savings available by use of EVA based upon historical probability data. As a side issue, historical contingencies were examined to establish a class which would have time-critical implications impacting the need to reduce EVA preparation time. The use of the term "contingency" in this study is limited to Shuttle payloads and is defined as meaning any unexpected operations or equipment failure which impacts the normal course of the mission. By ground rules for Shuttle payloads, no such failure can occur which would endanger the crew or the Shuttle orbiter vehicle. Maintenance and contingency analyses are discussed in Section II, and their cost data in Section IV.

The concerns frequently expressed in the payload community regarding the use of EVA can be expressed in two generalized questions: (1) What are the impacts on the payload (costs, design complexity)? and (2) What are the costs of acquiring and using an EVA capability? This subsection deals with these questions and briefly discusses contamination and EVA technology.

5.1 MAN-RATING

A totally objective evaluation of vehicle man-rating requirements and costs would require determining two alternate designs to meet mission objectives--manned or unmanned. In fact, of course, unmanned projects have only considered automated/mechanized functional performance. Manned programs were also single-minded from the start in major concepts, but did frequently involve lower-level trades. Some of these historical data furnished sources for defining man-rating cost elements. Boost vehicles such as Redstone, Atlas, and Titan were converted to man-rated boosters early in manned space flight.

It was recognized at the beginning of the Mercury program that the Atlas D launch vehicle would have to be modified in some areas[(1)]. A special study program was initiated to evaluate each system, concept of operation, and the effects of combinations of various failures that could conceivably occur. This program was called the *Pilot Safety Program*. There were some instances in which wiring or circuitry changes were made to improve system reliability. However, three major changes were accomplished. For instance, after ignition, the launch vehicle was intentionally held down for several seconds in order to determine that the engines were functioning properly. This change was a result of previous experience which showed that, after ignition, the engine performance could possibly become erratic (rough combustion) and cause destruction of the launch vehicle. The experience also showed that the additional hold-down time would provide sufficient time to detect such a malfunction and shut off the engines before liftoff, thereby preventing destruction.

Another system that was modified is the command destruct system. This system was changed to include a time delay circuit so that if a manual destruct command was sent to the launch vehicle, receipt of the command would immediately fire the spacecraft escape rocket motor; the destruct action of the launch vehicle would be delayed 3 seconds to allow the spacecraft time to escape from the launch vehicle.

The addition of the time delay circuit introduced the major modification made to the launch vehicle--the abort sensing implementation system (ASIS). This system was designed specifically for Project Mercury, and its purpose was to provide an automatic system that would sense specific quantities in the launch vehicle, detect when those quantities indicated impending catastrophe in the launch vehicle, and abort the spacecraft to escape the catastrophe. It was believed that the ASIS was necessary because some previous flights of the Atlas D had indicated that the time period between an indication of impending catastrophe and launch vehicle destruction could be extremely short--approaching the reaction time of a human being. It was decided therefore that an automatic system would be desirable, at least until more experience was gained on manned flights.

These data indicate cost areas in conventional boosters which do not affect either Shuttle payloads or upper stages for these payloads. Table 5-1 presents a matrix of such man-rating cost elements as summarized from recent past and current programs.

Manned vehicles such as Mercury, Gemini and Apollo, developed exclusively for manned flight, are analogous to the Shuttle orbiter. These vehicles were also involved in dynamic flight operations including atmospheric flight, entry, landing, and potentially pad abort--none of which applies to Shuttle payloads.

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(1) "Results of the First United States Manned Orbital Space Flight," Feburary 20, 1962, NASA-JSC.

Table 5-1. Man-Rating Requirements

FACTORS/PROGRAMS	MAN-RATING COST ELEMENTS: LIFE SUPPORT	VACUUM & RADIATION PROTECTION	THERMAL & METEOR PROTECTION	CREW REFUGE	RESCUE PROVISIONS	SAFE WORK STATIONS
PAST PROGRAMS						
APOLLO CSM	X	X	X	X	X	X
LEM	X	X	X	X	X	X
SKYLAB	X	X	X	X	X	X
CURRENT PROGRAMS						
INTERNATIONAL DOCKING MODULE	X	X	X	X		X
SHUTTLE	X	X	X	X	X	X
SPACELAB MODULE & P/L	X	X	X	X		X
SPACELAB PALLET & P/L						X
AUTOMATED SPACECRAFT						X
EVA PRESSURE SUIT	X	X	X			

The Lunar Module (LM) and the International Docking Module (IDM) have some analogy to the Spacelab module in that they are (partially at least) dependent upon another manned vehicle. The Apollo Telescope Mount (ATM) is comparable to Spacelab pallets and to automated spacecraft while they are installed in the Shuttle cargo bay. In terms of cost elements associated with man-rating, only compatibility with the *host* vehicle and safe crew interface or work station are requirements for Shuttle payloads. All other man-rating requirements (life support, protection, refuge and rescue) are provided by the Shuttle or Spacelab systems. The only *EVA chargeable* cost element is provision of whatever improvements are required to the payload safe work station.

In order to be accommodated on Shuttle or Spacelab missions, payloads must comply with a variety of safety rules, whether EVA is performed or not. In general, these involve equivalent safety provisions for flight and for ground crew personnel equivalent to any EVA provisions. These requirements are currently being defined in detail[1,2] but are summarized briefly in Table 5-2.

Some delta provisions potentially required for EVA may include additional consideration of load-bearing provisions for the EVA astronaut during zero-g activities and additional protection for delicate equipment or the pressure-suited crewman. Such protection could take the form of devices such as *ground covers* which provide protection for mechanics in analogous ground crew activities. Secondary power (ac) systems may require additional protection for EVA

[1] "Space Shuttle System Payload Accommodations, JSC 07700, Vol. XIV, Section 6.0, Safety Assurance for Space Shuttle Payloads.

[2] ERNO Modular Spacelab Safety Specification, SR-ER-0002.

interface when not connected to the Shuttle common ground; however, primary power systems will be provided with a return non-structural ground. EVA design provisions are discussed more thoroughly in Section II. EVA work-aids and tool or job-aid elements were included in study design, operations, and cost analyses.

Table 5-2. Currently Required Payload Safety (Man-Rating) Provisions

ELECTRICAL PROTECTION (HIGH VOLTAGE) POWER RETURN FOR ALL EQUIPMENT VIA HARDWIRE
STRUCTURAL PROVISIONS (SMOOTH/ROLLED EDGES, CORNERS) REQUIRED FOR ALL GROUND HANDLING OR TEST ACTIVITIES
HIGH-PRESSURE SYSTEMS (FLUIDS AND GASES) SEPARATED, SHIELDED, EMERGENCY SHUTOFF
RELIABILITY - ELECTRICAL AND MECHANICAL SYSTEMS FAIL-SAFE/REDUNDANCY WHERE CREW SAFETY IS A CONSIDERATION
FLUID HANDLING (FLUIDS AND GASES) NO HAZARDOUS CONDITIONS IN CARGO BAY POSITIVE SEALING DISCONNECTS

5.2 EVA PROVISIONS AND TRAINING

Shuttle baseline ensures a capability to utilize EVA on any payload mission. The system provisions (summarized in Section II) include the airlock, suits, backpacks and life support consumables necessary for two 2-man, 6-hour EVA's. However, questions are frequently raised among payload programs regarding costs to the payload for such equipment and for training of crewmen for EVA interface with the payloads.

To determine the availability of trained EVA crewmen on the Shuttle program, it was necessary to review current program criteria and planning. Shuttle program ground rules have established two EVA crewmen to be carried on each Shuttle flight. If one considers the current flight schedule planning (575 flights), as summarized in Table 5-3, and the crew necessary to support it, a total of about 120 crewmembers will be trained in EVA. This number was derived by postulating a maximum of five flights per man per year, no two consecutive flights, and an average of three operational years in the Shuttle program. Including a 10-percent EVA-trained crew for backup purposes, up to 20 additional man-flights per year should be available to payloads wishing to increase the number of EVA trained personnel available on orbit. While it is true that this is a generalized training, it should be noted that the Skylab astronauts performed almost as many unplanned EVA tasks as planned. The routine operations defined in this study also are particularly amenable to generalized training; e.g., use of standard latches, locking pins, etc. Data from Skylab indicate that planned tasks frequently involved only 1 to 2 hours of underwater

Table 5-3. EVA Crew Population Estimates

	YEAR												
	79	80	81	82	83	84	85	86	87	88	89	90	91
SHUTTLE OPERATIONAL FLIGHT SCHEDULE		8	15	24	48	60	60	60	60	60	60	60	60
MINIMUM EVA-MAN FLIGHTS		16	30	48	96	120	120	120	120	120	120	120	120
CREW TRAINED TO MEET FLIGHT SCHEDULE	6	2	6	14	8	6	14	8	6	14	8	6	14
AVAILABLE OPERATIONAL CREW		6	6	6									
			2	2	2								
				6	6	6							
					14	14	14						
						8	8	8					
							6	6	6				
								14	14	14			
									8	8	8		
										6	6	6	
											14	14	14
												8	8
													6
TOTALS		6	8	14	22	28	28	28	28	28	28	28	28
DELTA MAN FLIGHTS AVAILABLE		6	10	22	14	20	20	20	20	20	20	20	20

practice, so that even payload-unique training may not be a significant expense, although no Skylab cost data were available. Preliminary planning data (JSC) for Shuttle indicate that about $10,000 per flight will be required for complete EVA training of the crew, about 75 hours (ignoring fixed facility costs). Even with this amount of training, the cost to a payload for crew procedures, use of water immersion and simulator facilities, and EMU/equipment would only be about $5000 (one man); in fact, the training for payload tasks is generally expected to be considerably less than 75 hours.

In providing EVA-trained crewmen, the Shuttle program also provides EVA equipment. As discussed earlier, two sets of EMU (pressure suits and backpack) are Shuttle chargeable items on each flight. Additional EMU's (and consumables) can be carried to orbit, weight chargeable to payloads. Costs, if any, have not been established by the Shuttle program. The current Shuttle baseline provides an EMU at 4 psi with integral life support backpack and low mobility lower body assembly. Baseline provisions will include a manned maneuvering unit (MMU) for EVA free-flight operations. Some potential exists for advanced technology equipment which constitutes two of the issues involved with EVA. One of these issues relates to *quick-reaction* time, primarily relating to higher pressure extra vehicular mobility unit (EMU) which could be used to preclude pre-breathing. Section II presents relative timeline data for 4 and 8 psi suits as well as analysis of increased cost savings which could be attributed to quick reaction; e.g., increased experiment time in an EVA mode and response to time-critical contingencies. The second issue, overall mobility, was not evaluated in detail. However, in the process of examining the crew time sequences, especially for crewman translating through a maze of sortie payload experiments, his visibility and mobility should be the best possible to preclude damage to equipment or the EMU. EVA tool and interface developments are important to achieving the results defined in this study, and, therefore, offer an additional area for technology development.

In summary, it should be emphasized that an important consideration to the payload community regarding the cost of EVA is that basic equipment, training, and operation costs are STS provided. No payload personnel are to be trained in EVA per JSC's current position; however, EVA-trained crewmen could be given delta payload training. JSC documentation identifies an operational EVA level provided by the STS, but with the potential delta chargeable to the payloads. Similarly, if more than the two baseline crew were required to perform EVA on a given mission, the transportation of the additional crew and equipment could be expected to be payload chargeable. Training costs are not expected to be assessed unless some payload-unique/non-common tasks are required. Based upon analyses performed in this study, routine application of EVA can largely be accomplished within the level provided by the STS.

5.3 CONTAMINATION ISSUES

One of the issues frequently raised among payload personnel is concern over contamination caused by EVA crew. Various in-depth studies have been performed on sources and effects of contamination on payload sensors or equipment. EVA, as a source, has not been as thoroughly evaluated, and it was beyond the scope of this study effort to do so. However, it was decided to examine some aspects of this issue.

First of all, it must be realized that EVA is one of many sources, all of which are amenable to control techniques. The Skylab program was reviewed to gain insight into the Shuttle operations.

The Skylab plans for contamination control provide valuable data in comparison to actual experience. Plans included rigid control of organic materials to reduce outgassing, closeable sensor covers while scheduled venting or thrusting occurred, and self-contained pyrotechnic devices. A number of experiments were, however, affected--primarily due to launch or in-flight problems. A brief summary of problems from the Skylab missions shows that loss of the meteoroid shield at launch resulted in both direct particulate matter and, secondarily, in debris generated by heating of the now unprotected surfaces. On-orbit leakage failures added contaminant problems to some of the experiments. Table 5-4 provides a summary of data presented in more detail in a recent Skylab paper(1). The Shuttle program was assessed for comparable sources and, when available, magnitude of the contamination.

Table 5-4. Skylab Contamination Experience

EXPERIMENT	PROBLEMS	PROBABLE CAUSE
• ALL	• HIGH LEVEL OF RANDOM PARTICLES	• DEBRIS FROM METEOROID SHIELD FAILURE AND SOLAR HEATING
• IR SPECTROMETER	• CONTAMINATE DEGRADATION	• FAULTY COVER OPERATION
• UV X-RAY SOLAR PHOTOGRAPHY AND CORONA CONTAMINATION MEASUREMENTS	• DEGRADED	• BLOCKED BY THERMAL SAIL AND OPERATED EVA. POSSIBLE EVA CONTAMINATION
• THERMAL CONTROL COATING SAMPLE TRAYS AND MAGNETOSPHERIC PARTICLE COMPOSITION SURFACES	• SEVERE COLORATION AND CONTAMINATION	• COOLANOL LEAK
• FAR UV ELECTRONOGRAPHIC CAMERA	• CORONA INDICATIONS	• CABIN GAS LEAK
• UV STELLAR ASTRONOMY	• CONTAMINATION	• CABIN CONDENSATION - OPERATIONAL PROBLEM
• STAR TRACKER	• PARTICULATE CONTAMINATION - FALSE TRACKING	• METEOROID SHIELD FAILURE AND RESULTANT SOLAR BLISTERING

(1) The Skylab Results, Proceedings, Volume 1, AAS74-110, Skylab Contamination Control Techniques by C. M. Davis, MSFC, Sponsored by American Astronautical Society and U of Southern California Institute of Safety and System Analysis, August 20-22, 1974.

Table 5-5 lists gaseous effluent emission rates for representative orbiter sources. The vernier control system (VCS) stabilizes the orbiter by firing 25-pound thrusters. Combustion products are emitted at a rate of 40 grams per second from a single thruster when it is firing. For deadbands of 0.1 degree and larger, the average fuel consumption is 0.4 gram/second. Vented materials include gaseous hydrogen and oxygen and water vapor from fuel cell reactant tanks which are purged periodically. The emission rate shown for the EVA crewman is for current suit technology.

Table 5-5. Shuttle Operations Contamination

SCHEDULED SOURCES	EMISSION RATE GM/SEC	CONTROL TECHNIQUES
VENTING OF LIQUIDS & GASES	4.	STORAGE, VENT FILTERS, GEOMETRY/ LOCATION OF VENTS, SCHEDULING
WASTE MGMT (METABOLIC GASES)	0.007	GEOMETRY/LOCATION OF VENTS, STORAGE, SCHEDULING
WATER (MAX RATE PURE WATER)	3.8	STORAGE, CONTROLLED VENTING
CREW EVA		
LEAKAGE (BREATHING GASES)	0.004	PARTIAL SHROUD, SUIT TECHNOLOGY
VENTING (WATER VAPOR)	0.22	DIRECTIONAL CONTROL, ROUTING
MOTOR FIRINGS		
ORBIT ADJUST PER ENGINE	8626	SCHEDULING, COVER SENSORS
RCS - MIN PULSE PER ENGINE (40 MS)	1450	SCHEDULING, COVER SENSORS
- MAX DURATION PER ENGINE (500 SEC)	1453	GEOMETRY, SHROUDS, SCHEDULING
UNSCHEDULED SOURCES		
NON-METAL MATERIALS OUTGASSING AT 100 C (RTV) PER CM^2 PER SEC	VARIABLE	TYPICAL, 5×10^{-10} $GRMS/CM^2/SEC$ (RTV 560). MATERIAL SELECTION, REDUCE SURFACE AREA, LOCATIONS
CREW ATMOSPHERE LEAKAGE	0.04	UNCONTROLLED
MOTOR FIRINGS		
STABILIZATION & CONTROL	40.	GEOMETRY, SHROUDS, SCHEDULING

It can be seen that the EVA crewman thus introduces a very small increase in the local contamination environment. But this source is localized in the cargo bay and, in some cases, protective measures should be taken. For example, exposure of cryogenically-cooled surfaces to this source should be prevented. Extensive monitoring is planned of the orbiter cargo bay contamination environment early in the Shuttle program. Early use of EVA will establish the significance of this source in the overall area of payload contamination. Advanced technology suits can potentially reduce the leakage levels well below that listed on the table, which corresponds to 200 standard cubic centimeters per minute. Additional control means for EVA have been proposed as noted.

Contact was made with two authorities on the subject during the course of the study. Dr. Robert Nauman[1] was contacted to discuss philosophy concerning EVA sensor optics cleaning and removal of contamination shields from automated spacecraft prior to release from the Shuttle.

Dr. Nauman firmly feels that removal of contamination shield would not (or should not) degrade sensor optics for the short period of time in the vicinity of the Shuttle prior to spacecraft release (probably one hour uncovered). IR sensors may be a problem since much water vapor and other condensible material tends to remain in the vicinity of the Shuttle. The problem is with condensation on cold surfaces.

There should be no problem with contamination during injection to another orbit. Dr. Nauman feels that since the optics are required to function adequately on orbit, that they should survive an orbit transfer in the uncovered condition.

With regard to on-orbit cleaning--Dr. Nauman is of the opinion that if a sensor is so contaminated as to require cleaning, it should be returned to earth for proper cleaning. This philosophical point is based in part on the fact that by the time these payloads are scheduled to fly the contamination problem should be thoroughly understood and prevented rather than cleaned up on orbit.

Roger Gillet did a study on this subject, but it concentrated on cleaning hydrocarbons (by plasma gas jet) which is not a serious condition in space. The real problem is with silicones which do not oxidize and are difficult to clean. No suitable on-orbit cleaning method was identified during the course of this study.

A brief discussion was also held with Dr. L. Leger of JSC by the study technical monitor, study manager, and his deputy.

It was a general conclusion of the study that the EVA crewman produces a small and controllable contribution to the contamination level in the Shuttle, and that contamination covers can, selectively at least, be manually removed for on-orbit operations.

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[1] Private communication between Dr. Robert Nauman (NASA-MSFC) and E. F. Kraly (Rockwell).